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The Rise and Fall of the Ornamental Callery Pear Tree

Theresa M. Culley

One of the most notable heralds of spring in the eastern United States is the profuse blooming of ornamental pear trees in front yards and along city streets. The Callery pear (*Pyrus calleryana*), and particularly its many cultivars such as 'Bradford', 'Cleveland Select', and 'Aristocrat', has become one of the most popular ornamental trees in North America. However, its commercial success has now become overshadowed by its tendency to spread along roadways and into natural areas through reseeding. Today this tree is considered invasive in many states, in stark contrast to how it grows in its native range in Asia. How did this tree become the scourge of land managers across North America? What has led to its fall from grace? To understand this fascinating story, we need to start at the beginning.

ARCHIVES OF THE ARNOLD ARBORETUM

Plant collector Frank N. Meyer in China in 1908.

Seeds From China

Toward the end of the nineteenth century, farming began to replace ranching in the western United States and there was a growing demand for improved crops that could thrive there. The United States Department of Agriculture (USDA) began to focus on importing new plants for testing and, in 1898, created the Foreign Seed and Plant Introduction Office. The mission of this office, headed by David Fairchild, was to locate and import economically important plants from other regions of the world. Fairchild was especially interested in China, which was thought to possess a wealth of unexplored botanical resources. Chinese plants were also expected to grow well in the United States because China's climate is very similar to that in the United States.

In the early 1900s, Fairchild began searching for plant explorers who had the dedication and stamina to tolerate the physical discomforts and social isolation of travelling for months in distant lands. He found Frank N. Meyer (1875–1918), a Dutch immigrant and former gardener who had a deep fascination with plants and saw nothing unusual about walking hundreds of miles on a botanical foray. Meyer eventually spent over ten years traveling across Asia looking for useful and valuable plants, seeking, in his own words, to "skim the earth in search of things good for man." He eventually sent hundreds of shipments of cuttings and thousands of pounds of seeds back to the USDA. Many agricultural crops grown in the United States today, including certain grains, legumes, and fruits, resulted from Meyer's collections.

But before he began his first Chinese expedition in 1905, Meyer visited several United States gardens to become familiar with Chi-

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Ernest H. Wilson made this photo of a 40-foot-tall *Pyrus calleryana* tree in a Chinese botanical garden on April 7, 1909.

nese plants in their collections. He was most impressed with the Arnold Arboretum's collection and he met director Charles Sprague Sargent, who was keenly interested in Meyer's travels but who also had a complex and often difficult relationship with Fairchild. Meyer clearly respected the Arnold Arboretum—he once requested that his Chinese material be sent there instead of to a USDA station because he felt it would receive better care. However, Meyer's relationship with the Arnold's plant explorer Ernest H. Wilson was somewhat uneasy at first, likely because they first viewed each other as competitors since Sargent had also asked Meyer to collect for the Arboretum during his Chinese expeditions. While Meyer was willing to oblige, this arrangement would sometimes place Meyer in an awkward situation because Sargent's emphasis on capturing the diversity of the Chinese flora was often at odds with Fairchild's directive to focus only on economically important species.

The search for new plants from other countries became more urgent in the early 1900s when valuable orchards of the edible French pear (*Pyrus communis*) were being decimated by fire blight in the Pacific Northwest. This bacterial disease blackened leaves and branch tips of infected trees as if they were scorched by fire, eventually killing large fruit trees, and it was quickly spreading throughout the region. In the hopes of breeding resistance to fire blight into *P. communis*, Professor Frank C. Reimer of the Southern Oregon Experiment Station hastily began testing all available *Pyrus* species and varieties for resistance to this devastating disease. The initial results proved disappointing, so a call was put out to locate *Pyrus* species in

This 1890 USDA illustration shows a stem of the edible pear (*Pyrus communis*) cultivar 'Le Conte' that had been inoculated with fire blight bacteria twelve days prior. The terminal "shepherd's crook" and blackened leaves are characteristic of fire blight. From the USDA Pomological Watercolor Collection, National Agricultural Library, Special Collections.

other parts of the world that might be fire blight resistant. Many plant explorers, including E. H. Wilson and Emil Bretschneider, traveled to Asia in the early 1900s, in part to locate new *Pyrus* species, often with the material sent back to the Arnold Arboretum. In 1908, Wilson first introduced *P. calleryana* into the United States with several seed lots accessioned and grown at the Arnold Arboretum.

In 1916, between his Chinese expeditions, Meyer visited the Pacific Northwest where he saw for himself the extensive fire blight destruction. He now understood the importance of his work because he learned from Reimer that resistance had only been found in the wild Chinese pear species *P. calleryana* and *P. ussuriensis*. However, Reimer needed more material for testing and Meyer agreed to collect and send back over 100 pounds of wild *P. calleryana* seeds during his next expedition. This was no small task since 25 pounds of cleaned seeds required at least 5,000 pounds of fruit.

During his subsequent months in China, Meyer focused much of his effort on *Pyrus calleryana*. He painstakingly collected thousands of the marble-sized pear fruits in the field or bought them directly from local Chinese. He later wrote Fairchild that:

> *Pyrus calleryana* is simply a marvel. One finds it growing under all sorts of conditions; one time on dry, sterile mountain slopes; then again with its roots in standing water at the edge of a pond; sometimes in open pine forest, then again among scrub on blue-stone ledges in the burning sun; sometimes in low bamboo-jungle … and then again along the course of a fast flowing mountain stream or in the occasionally burned-over slope of a pebbly hill. The tree is nowhere found in groves; always as scattered specimens, and but very few large trees were seen.

In 1917, Reimer himself joined Meyer in China and they traveled together for several days, with Meyer showing Reimer the locations of *Pyrus calleryana* trees he had found. In his report, Reimer's amazement at this plant is evident, which also heralded his eventual emphasis on the species as rootstock:

> In its ability to endure diverse and adverse soil conditions, this species certainly is a marvel … I found it growing in all the various soil types … ranging from heavy clays to light sandy soils and disintegrated rock. I found it growing in shallow ponds, along streams, well-drained moist loams, and on very dry poor hillsides and hilltops. In places it was observed where the layers of soil above the bedrock was not more than eight inches deep.

USDA NATIONAL AGRICULTURAL LIBRARY, SPECIAL COLLECTIONS

Flowers, leaves, and fruits of *Pyrus calleryana* collected in China and photographed by Frank Meyer in April 1917. Meyer's description of the photo from his South China Exploration typescript: "*Pyrus calleryana*, natural size. A somewhat small-flowering type of a wild Calleryana pear, with rather tomentose foliage, which isn't full grown yet. Three fruits of last year's crop has persisted on the tree during the whole winter and spring. Note the very small size, on which account the Chinese call it the "T'ang li" or crab-apple pear, as these small fruits, with deciduous calyx, resemble the tiny apples of *Malus spectabilis* and *M. baccata* to a surprising degree."

USDA NATIONAL AGRICULTURAL LIBRARY, SPECIAL COLLECTIONS

Frank Meyer photographed the environmentally adaptable *Pyrus calleryana* growing in a number of distinct habitats in China including along waterways with roots in standing water, in crevices in shale rock, within a dense jungle of bamboo, and, seen here, in shrubby, dwarfed form on a dry mountain top.

THE ARNOLD ARBORETUM

Herbarium specimen of *P. calleryana* growing at the Arnold Arboretum in May 1918. The tree was grown from seeds collected in China by Ernest H. Wilson in April 1908.

Reimer also saw that under favorable conditions in China, the tree "is a rapid, vigorous grower, has a long growing season, and its leaves remain green and lusty until very late in the fall." In central China, the trees were often cut off for firewood every few years but they would put out "new sprouts from the stumps and continue to live for many years." These wild trees also typically produced prominent thorns (actually sharp spur shoots) that effectively protected against herbivory. The species seemed to be adapted to mild climates, with Reimer suggesting, "It is quite probable that it will not endure very severe winter climates." However, he also wrote that trees that originated from China had proved to be very hardy at the Arnold Arboretum over 10 years, despite the more severe winters near Boston compared to the native range in China.

Upon his return, Reimer continued to work with other plant explorers to obtain *Pyrus calleryana* seeds for further testing. Tragically, Meyer never returned to the United States, drowning in the Yangtze River in late 1918 just as he was beginning his trip home. However, his much-anticipated collection of *P. calleryana* seeds was shipped back in his absence, to complete the task that he had begun years earlier. It is from many of these seeds that our story continues.

'Bradford', the First Callery Pear Cultivar

Over the next few years, Chinese seeds collected by Meyer and Reimer were planted in large numbers—primarily at the USDA Plant Introduction Stations at Corvallis, Oregon, and Glenn Dale, Maryland—to test their resistance to fire blight. Over time, interest in the species turned to its ability to serve as rootstock for the economically valuable edible French pear. For example,

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"Thorns" are naturally produced by both Callery pear trees in China and wild trees in the United States. This structure is technically a spur, a short, pointed shoot bearing leaves or flowers. Most Callery pear cultivars were selected in part for thornlessness.

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A typical 'Bradford' Callery pear flowering in early spring. This tree has already lost a limb and the homeowner has tied straps around the inside branches in an attempt to prevent further breakage.

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A 'Bradford' tree in West Chester, Ohio, that split during the winds of Hurricane Ike in September 2008.

Reimer wrote that "thousands of seedlings have been grown" in the Pacific Northwest from Meyer's original seed "to test this species thoroughly as a stock for our cultivated varieties." In Glenn Dale, Meyer's seeds were also planted out in large numbers to test the plants for resistance to fire blight, overall vigor, and stock-scion compatibility with *P. communis.*

In 1952, one of the remaining 33-year-old trees of *Pyrus calleryana* from Meyer's Chinese seeds that was still growing near the Plant Introduction Station in Glenn Dale caught the eye of John Creech of the USDA (Creech 1973). This tree had thick, glossy leaves and an attractive globular form, with a lack of sharp spurs so typical of the species. Recognizing its potential as a landscaping tree, Creech grafted scions of it onto *P. calleryana* rootstock. This method of propagation means that every tree is genetically identical to the original mother tree. Creech named this cultivar 'Bradford', in honor of F. C. Bradford, the former horticulturist in charge of the Glenn Dale USDA station (Whitehouse et al. 1963). (Incidentally, the original 'Bradford' tree was destroyed years later to make way for a parking lot).

In 1954, Creech planted two-year-old 'Bradford' clones in a nearby residential subdivision in University Park, Maryland, for a street tree study. 'Bradford' swiftly became quite popular for its rapid growth, attractive foliage that was retained into late fall, extremely showy and abundant flowers in early spring, and its overall hardiness. The cultivar was commercially released around 1961 and then planted widely across the eastern United States in residential areas.

However, by the early 1980s problems with 'Bradford' pears began to appear, especially a tendency for older trees to break apart during windstorms or under heavy snow loads. Its branching structure was to blame, as described by horticulturist Michael Dirr (1998), "'Bradford' tends to develop rather tight crotches and I have seen trees that were literally split in half ... the plant

will … fall apart because of the development of many branches around a common length of the trunk."

More Callery Pear Cultivars Appear

Over the next few decades, additional *P. calleryana* cultivars were quickly introduced as improved replacements for older 'Bradford' trees that had begun to split. For example, 'Whitehouse', a narrow columnar form with a strong central leader, was selected in 1969 from seedlings still growing near the Plant Introduction Station in Glenn Dale. This cultivar presumably began as a seed from the original 'Bradford' tree that had been pollinated by one of the other wild *P. calleryana* plants at the station. Similarly, 'Redspire' also arose as a 'Bradford' seedling and was patented in 1975.

At the opposite side of the country, 'Autumn Blaze' was selected in 1969 from among several hundred seedlings of *P. calleryana* growing at the rootstock research nursery in Corvallis. This cultivar, known for its striking red to purple leaf coloration in the fall, originated from seeds that Reimer had brought back from China during his trip with Meyer in 1917 or later in 1919. Other cultivars such as 'Avery Park' and 'Grant St. Yellow' also originated in the late 1960s and 1970s near Corvallis, most likely from Chinese seeds imported into that area.

Over time, additional cultivars arose from other areas of the country, presumably from different seed sources. For example, 'Aristocrat' arose in Independence, Kentucky, while the cultivars 'Cleveland Select', 'Chanticleer', and 'Stone Hill' were all derived from the same street tree in Cleveland, Ohio. The cultivar 'Valzam' was found growing among 'Cleveland Select' trees in Perry, Ohio in 1975—most likely an offspring of that cultivar but with unknown paternity.

LESLIE J. MEHRHOFF, UNIVERSITY OF CONNECTICUT, BUGWOOD.ORG

Fall foliage color on Callery pear cultivars and seedlings ranges from yellow to bright red and purple.

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Callery pear cultivars became extremely popular as urban street trees in the eastern United States.

These and other Callery pear cultivars became exceedingly popular as ornamental landscaping trees for residential and commercial use. Not only were they beautiful, fast growing, and inexpensive, but they were also extremely tolerant of very difficult growing conditions. In commercial areas, for example, the tree could thrive in the harsh conditions of parking lot islands and between streets and sidewalks,

where temperatures were excessively high and water was scarce. Following the tragic events of September 11, 2001, when the World Trade Center's twin towers fell in New York City, a Callery pear tree at the site was found still alive but severely burned with damaged roots and branches. Known today as the "Survivor Tree," it was rescued from the site, taken to a local nursery to recover, and later replanted back in the memorial park at Ground Zero as a symbol of resilience.

In 2005, 'Chanticleer' was chosen as the Urban Tree of the Year by the Society of Municipal Arborists, who noted that, "This tree has all of the character and quality of a sheared topiary specimen plus, of course, the magnificence of its spring, summer, and fall outer garments—the white flower, crisp glossy green summer foliage, and full fall color." Some homeowners associations in areas of the United States even had a requirement that a specific Callery pear cultivar had to be planted in each front yard. In fact, the Callery pear had become so popular that Michael Dirr lamented in 1989 that "cookie-cutter Bradfords … inhabit almost every city and town to some degree or another; the tree has reached epidemic proportions and is over-planted." In 2009 alone, the species generated over $23 million in sales across the country (USDA 2010), including continuing sales of 'Bradford'. Although the majority of commercial sales occurred in the eastern and southern United States, cultivars were also available along the western coastal states. The tree had reached its epitome of fame and glory.

The Fall From Grace

As 'Bradford' and other Callery pear cultivars surged in popularity, early indications of problems began to appear. *Pyrus calleryana* had escaped cultivation as early as 1964 in Arkansas and 1965 in Maryland (Vincent 2005), but it was not until the 1990s that the species began to be more widely noticed in natural areas, especially in southern states. For example, Michael Vincent of Miami University (Ohio) examined 300 *P. calleryana* herbarium specimens collected across the nation beginning in 1964. He found that 1% of all specimens were collected in each of the periods 1964–1969 and 1970–1979 before a dramatic increase began in 1980–1989 (17% of all specimens), continuing through 1990–1999 (31%), and mounting rapidly in the last three years of the study, 2000–2003 (50%). By the late 1990s, members of several Internet gardening forums began noting the increasing numbers of wild pears beside roadways along the mid-Atlantic coast, largely in the Maryland area.

By the middle of the twenty-first century's first decade, thousands of young wild pear seedlings were growing undetected in the roadside vegetation across the southern and eastern United States. But as they began to flower in their third or later year, their profuse early spring blooms started to give them away. As each successive year revealed more and more wild pears blooming, public alarm began to sound. Land managers began to notice wild pears appearing in all types of habitats—along forest edges, in wetland areas, and even within forests. This is not surprising given Meyer's and Reimer's remarks about the many different habitats where *P. calleryana* is found in its native range. In the United States, word eventually began to spread of not only the slippery mess caused by pear fruits littering sidewalks, the difficulty in removing dense stands of thorny trees in natural areas, and the putrid smell of the flowers, but also increasing concern of liability caused by falling tree limbs damaging property and injuring people. *Pyrus calleryana* (often indicated as just "Bradford pear") began to appear on watch lists and invasive plant lists in several eastern and southern states. But why had this pear, which had behaved for decades as a popular landscaping tree, suddenly start to spread uncontrollably?

The answer lies in the reproductive system of the species as well as its horticultural history. As with most other pears, *Pyrus calleryana* has a genetically controlled self-incompatibility system that prevents individual trees from pollinating themselves, thus requiring outcrossing among unrelated individuals. When 'Bradford' was first introduced and became so wildly popular, 'Bradford' trees were unable to cross-pollinate (since they were all genetically identical) and fruits were never produced. As additional cultivars were introduced they were often commercially marketed as "self-sterile"

JOE BOGGS

Invasive population of wild Callery pears grows in a field next to Interstate I-75 in Butler County, Ohio.

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When two or more Callery pear cultivars are planted nearby, abundant fruits are usually produced.

or even "seedless"—this was true, as long as each cultivar was grown in isolation. Cultivar patents and promotional material included notes such as "[fruit set] very low (about 5 to 10%), usually only one fruit per cluster" ('Autumn Blaze'); "little or no fruit and the fruit that is produced is small and hard" ('Trinity'); and "self-sterile" with fruits typically not abundant and only produced when "planted near another clone"('Aristocrat'). The last point is the lynchpin of this story.

Although each Callery pear cultivar cannot produce fruits on its own, fruits can easily develop when two or more cultivars—which are genetically different and therefore cross compatible—are planted together (Culley and Hardiman 2007). Cross-pollination is promoted by insect pollinators, especially bees, which frequently fly over a mile each day visiting all flowers within their range. This has a large impact on the magnitude of the pear problem. For example, if a large residential area only contains 'Bradford' trees, no fruits would be formed. But if a new resident moves in and plants a single 'Aristocrat' in her yard, that new tree now has the potential to cross-pollinate *all* the 'Bradford' trees within a mile-wide range, and vice-versa. This could trigger a sudden outburst of fruit within a single year. Such massive fruiting may even go undetected at first because some people expect any pear, including *P. calleryana*, to produce large edible fruits like a 'Bartlett' pear, and they do not recognize the small fruits of Callery pear.

During the winter months, these fruits are consumed by birds that then defecate the seeds as they fly or roost in trees or along power lines, thereby spreading the species into new areas. In fact, genetic analysis of new wild Callery pear populations have confirmed that wild plants are typically F1 hybrids of cultivars planted in the surrounding residential and commercial areas (Culley and Hardiman 2009). In older populations, such as near the Glenn Dale station where 'Bradford' was first discovered, wild pear populations largely consist of advanced generation hybrids.

Cross pollination between mature specimens of Callery pear cultivars is not the only way fruit production can occur. To maintain their genetic identity, Callery pear cultivars are clonally produced by vegetative propagation. Stem cuttings of Callery pears are difficult to root so most trees are propagated for commercial sale by grafting. In this process, the scion material of the selected cultivar is grafted onto

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A flock of European starlings (*Sturnus vulgaris*) eats Callery pear fruits in a parking lot.

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The rootstock of commercially grafted Callery pear trees can occasionally sprout. If left to grow and flower, the rootstock can cross-pollinate the upper scion of the tree.

rootstock, which is usually *P. calleryana* seedlings. The two sections grow together, resulting in a tree composed of two genotypes. Occasionally, the rootstock of a planted Callery pear cultivar may develop shoots that eventually flower. In such a case, the rootstock now has the potential to cross-pollinate the upper scion *of the same tree,* triggering fruit production. So it is possible for a wild population of pear trees to come from a landscape planting of multiple cultivars or even from a single grafted tree. In a genetic parentage study of a wild Callery pear population in southwestern Ohio, it was discovered that at least 17% of wild trees had a rootstock parent (Culley et al. 2011).

The Future

The introduced range of *Pyrus calleryana* in the United States is currently restricted by the species' limited cold tolerance, as predicted decades ago by Reimer and Meyer. However, hardier cultivars are now being developed that will expand Callery pear's landscape presence. In addition, wild Callery pear is expected to continue to spread northward as global climate change causes shifts in warmer temperatures. In fact, wild Callery pears have already been observed around Madison, Wisconsin (USDA Hardiness Zone 5a), an area where they were thought never to survive.

What can be done to prevent the continued spread of the wild Callery pear? First, Callery pear cultivars need to be carefully phased out of commercial production and replaced with suitable alternatives. The latter is critical, as it would allow plant breeders and the nursery industry to recoup any economic loss and remain profitable. In fact, sterile varieties of *P. calleryana* are currently being developed. Second, as cultivated trees within the landscape break apart or decline they should be replaced with these alternatives. This is something already happening in many towns nationwide, as Callery pears are being replaced with different tree species. Finally, if homeowners choose to keep cultivated Callery pears growing in their yards, they must take responsibility for ensuring that fruits are not produced. Callery pear fruit production can be reduced as much as 95% by spraying flowering trees

with ethephon, a plant growth regulator that does not affect the flowers' appearance but does make them incapable of developing into fruit. But even if all these suggestions could be accomplished, the sad reality is that wild Callery pear will continue to be a growing problem in the years to come because so many cultivars and their rootstock are already established in the landscape.

Today, the Callery pear story is another example of how even the best of human intentions can go awry. The pear was introduced into the United States for the best of reasons—to save the valuable crop of *P. communis* on the West Coast from fire blight in the 1920s. Decades later, 'Bradford' and other Callery pear cultivars were selected and promoted to give gardeners and landscaping professionals additional highly tolerant and attractive trees for the landscape. These were all good and sensible ideas at the time, especially since the majority of introduced species in the United States never become invasive. The resulting spread of wild *P. calleryana* into the American landscape was unanticipated and completely unintentional. The best that we can do today is to view the Callery pear as a lesson on the importance of considering how mixes of ornamental cultivars may contribute to invasive spread of certain species. By learning from our past history, we can better understand why certain species become invasive, and thus we can work more effectively to prevent invasive spread of species in the future.

Acknowledgments

The author would like to thank the many researchers, land managers, nursery professionals, and students who were invaluable in uncovering this story. Most notably, this project was sparked by Marjie Becus, who first pointed out wild Callery pear to the author during their vegetational rambles, and Robert Naczi, who mentioned the Internet discussion on the topic shortly after. The author also thanks Joe Boggs and Michael Vincent for their willingness to share their thoughts and expertise, as well as Larissa Glasser for locating Frank Reimer's original notes in the Arnold Library. This article is dedicated to the memory of Sarah Elizabeth Reichard, who was instrumental in highlighting the importance of horticultural introductions in plant invasions as well as the necessity of working with nursery interests to create practical and effective solutions. She will be missed.

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Plant Dye Identification in Japanese Woodblock Prints

Michele Derrick, Joan Wright, Richard Newman

Figure 1. *Actors Sanjō Kantarō II and Ichimura Takenojō IV,* (MFA 11.13273), about 1719 (Kyōho 4), designed by Torii Kiyotada I, and published by Komatsuya (31.1 x 15.3 cm). Example of a *beni-e* Japanese woodblock print with hand-applied color commonly made from the 1650s to 1740s.

Woodblock prints were first produced in Japan during the sixth to eighth century but it was not until the Edo period (1603–1868) that the full potential of woodblock printing as a means to create popular imagery for mass consumption developed. Known broadly as *ukiyo-e,* meaning "pictures of the floating world," these prints depicted Kabuki actors, beautiful women, scenes from history or legend, views of Edo, landscapes, and erotica. Prints and printed books, with or without illustrations, became an integral part of daily life during this time of peace and stability. Prints produced from about the 1650s through the 1740s were printed in black line, sometimes with hand-applied color (see figure 1). These colors were predominantly mineral (inorganic) pigments supplemented by plant-based (organic) colorants. Since adding colors to a print by hand was costly and slowed production, the block carvers eventually hit upon a means to create a multicolor print using blocks that contained an "L" shaped groove carved into the corner and a straight groove carved further up its side in order to align the paper to be printed (see figure 2). These guides, called *kento,* are located in the same location on each block. They ensure consistent alignment as each color is printed onto a single sheet of paper.

From the 1740s to about 1765, the first block printed colors appeared on simple two- or three-color images (see figure 3). These *benizuri-e* ("red pictures") utilized red, blue, or yellow; sometimes these colors were over-printed to create the secondary colors purple, orange, and green. From 1765 on, the skills required to use the *kento* registration system reached a level where several color blocks could be expertly printed and full-color *nishiki-e* or "brocade prints" such as those designed by Suzuki Harunobu (1725–1770) became the standard

Figure 2. A Japanese woodblock that illustrates the 'L' shaped *kento* groove added in the corners of each block to aid in the alignment of the paper for printing multiple colors.

(see figure 4). Vibrant full-color prints designed by well-known artists such as Torii Kiyonaga (1752–1815) and Kitagawa Utamaro (1753–1806), produced and marketed by the great publishing houses of Tsutaya Jūzaburō and Nishimura Yohachi, defined the period from 1781–1801, which is often referred to as the Golden Age of the Japanese woodblock print (see figures 5 and 6).

Figure 3. *Actor Ichikawa Danzō III as Adachi Hachirō*, (MFA 11.19030), 1762 (Hôreki 12) 11th month, designed by Torii Kiyomitsu I, and published by Urokogataya Magobei (30.2 x 14.2 cm). Example of a *benizuri-e* Japanese woodblock print with a 3-color palette commonly made from the 1740s to 1765.

Figure 4. ***Courtesan Watching Two Kamuro Make a Snow Dog,*** **(MFA 21.4463), about 1767–68 (Meiwa 4–5), designed by Suzuki Harunobu (28.5 x 21.8 cm). Example of full color printing,** ***nishiki-e,*** **characteristic of the early years from 1766–1780.**

Japanese Woodblock Prints at the MFA

The Museum of Fine Arts (MFA), Boston, holds a collection of over 50,000 Japanese woodblock prints and illustrated books. This represents the largest number of such art works in a single location outside of Japan.

In 2010, a major five-year project to accession, image, and re-house this vast collection of Japanese woodblock prints was completed with cataloguing ongoing. This project placed information about each print along with its image and the translation of any Japanese text, signatures, and seals on the print into the Museum System collections database (TMS), enabling our current research as well as numerous exhibitions and publications. Of additional significance, the collection holds a number of multiple impressions of a single image, thus providing an ideal setting to identify, survey, and understand the organic and inorganic colorants used in traditional Japanese color woodblock printing.

In 2013, the Asian Conservation and Scientific Research divisions began a large-scale survey of the colorants used in the MFA collection of Japanese prints. This effort uses only non-destructive techniques, which means no samples are required of the prints that are formed by minimal levels of colorants absorbed into their paper fibers. The first two techniques used for this study are standard methods used in museum labs: X-ray Fluorescence (XRF) and Fiber Optic Reflectance Spectroscopy (FORS). A new and previously little-used technique of Excitation-Emission Matrix (EEM), or 3D, fluorescence spectroscopy was also used to successfully characterize several additional dyes.

Colorants

The plant-based red, yellow, and blue dyes long considered to make up the palette of Japanese woodblock prints are summarized in Table 1. The list is based on various published sources, including early Japanese literature and analytical studies, and may not be comprehensive. The inorganic pigments used in the prints, such as red lead, hematite, and orpiment, can be easily estimated by XRF (see Table 2). The traditional organic blues, dayflower and indigo, can be confidently identified by FORS in the visible and near-infrared ranges. Both XRF and FORS were used in the examination of the prints discussed in this article. The unique component of this study was the use of EEM fluorescence spectroscopy to identify the yellow and red natural

Figure 5. ***Actors Matsumoto Kōshirō IV as Ukita Sakingo and Sawamura Sōjūrō III as the Ghost of Takao, with chanters Tomimoto Itsukidayû and Tomimoto Awatayû, and accompanist Sasaki Ichishirô,*** **(MFA 11.13921), 1788 (Tenmei 8) autumn, designed by Torii Kiyonaga and published by Nishimuraya Yohachi (38.8 x 26.8 cm). Example of full color printing, *nishiki-e*, characteristic of Japanese woodblock prints made from 1781 to 1801.**

organic colorants on the prints. Examples of the color and line contour maps obtained as results for the fluorescence analysis are shown in Tables 3 and 4.

For this project, it was important to obtain reference materials from documented sources for each of the materials to determine the best method for its identification. Once the reference samples were obtained, they were authenticated using Liquid Chromatography with a Mass Spectrometer detector (LC/MS). Afterward, each material was prepared by historical methods, then printed onto Japanese paper. For the materials listed in Table 1, all were available from documented sources as raw materials, except for Toringo crabapple (*Malus sieboldii*) and *Coptis japonica*, Japanese goldthread, a member of the buttercup family. Fortunately, the Arnold Arboretum generously supplied samples of branches from five *Malus sieboldii* specimens in their collection. In lieu of *C. japonica*, a sample of threeleaf goldthread (*Coptis trifolia*), a related species native to North America, was obtained from a biologist in Vermont.

Results

An initial set of 213 Japanese woodblock prints were examined at the MFA by the combined techniques of XRF, FORS, and EEM fluorescence. These prints covered the time period 1700 to 1800 (see Table 5). The goal for the analysis of the prints was to obtain an overview of the colorants used by artists active in each time period; this goal was later expanded to include information on publishers, since they were probably responsible for the final colorant decisions. Our research is ongoing and is conducted as time allows. It is hoped that the analysis of a more extensive set of prints will provide definitive information on the relationships between colorants, publisher, artist, and period. (See Table 6 for the results from the example prints mentioned in this article.)

Even with this limited data set, several patterns of colorant use were consistently found for the eighteenth century time period. From the beginning, it was clear that the prints often contained more than one yellow, red, or blue colorant. Though it seems logical, since each colorant has unique tonal properties, this finding was significant in terms of analysis, indicating it was imperative to analyze multiple colored regions for each print. Because of the

PLANT SOURCE	JAPANESE NAME	COMMON ENGLISH NAMES	PART OF PLANT USED	COLOR
Caesalpinia sappan	*suo, suwo*	sappanwood	heartwood	red
Carthamus tinctorius	*benibana*	safflower	florets separated from capitulum	red
Rubia akane	*akane*	Japanese madder	roots, stems	red
Rubia tinctorum	*seiyo-akane*	European madder	roots, stems	red
Berberis thunbergii	*megi*	Japanese barberry	roots, stems	yellow
Coptis japonica; C. trifolia	*woren*	goldthread	roots, stems	yellow
Curcuma longa (syn. *C. domestica*); *C. aromatica*	*ukon*	turmeric	rhizomes	yellow
Gardenia jasminoides (syn. *G. augusta*)	*kuchinashi*	gardenia	juice or extract from fruit	yellow
Garcinia hanburyi, G. morella	*shio, te-o; kusa shio*	gamboge	resin/powder	yellow
Malus sieboldii (syn. *Pyrus toringo*)	*zumi*	Toringo crabapple	bark	yellow
Miscanthus tinctorius; M. sinensis	*kariyasu*	silver grass	grass cut when flowering spikes form, then dried over the winter	yellow
Myrica rubra	*yama-momo*	mountain peach, red bayberry	bark	yellow
Nandina domestica	*nanten*	nandina, heavenly bamboo	branch	yellow
Phellodendron amurense	*kihada*	Amur corktree	inner bark of trunk	yellow
Styphnolobium japonicum (syn. *Sophora japonica*)	*enju*	Japanese pagoda tree	unopened flower buds	yellow

Table 1. Common Asian natural red and yellow organic colorants in Japanese woodblock prints.

expansion to the use of mixtures and colorant variations from 1781 to 1801, it was common to find three types of yellow, two reds, and two blues in a single print (example figure 5). Thus, while 213 prints were studied, there were over 1,500 individual analysis points.

As expected from the literature, safflower (*Carthamus tinctorius*) was the primary red and pink colorant used consistently for all of the time periods and methods of application. Surprisingly, however, the second most prolifically used red was madder. While the analytical methods used in these tests, could not distinguish between Japanese madder (*Rubia akane*) and European madder (*Rubia tinctorum*), one or both of these colorants were consistently found

on prints in all four of the described periods with their use increasing from 20% up to 50% over the hundred-year period.

The yellow colorants changed significantly over the hundred-year period from the sole use of flavonoids and gamboge during the *beni-e* hand-applied color period (1710–1740s) to the predominant use of turmeric and orpiment (an arsenic sulfide mineral) for the elaborate designs and techniques used for full color printing from 1781–1801.

Inorganic pigments were found on most prints examined for each time period. While the use of orpiment (As_2S_3) increased significantly, the use of hematite (an iron oxide, Fe_2O_3) and lead (Pb) were constant. Other inorganic pigments were occasionally found, such as added decorations using ground metallic brass (figure 1). Vermilion, a mercury-containing pigment commonly used for paintings, has been mentioned as a definitive colorant in Japanese printing. However, this study found only two prints containing vermilion, indicating it may not have been commonly used.

Of interest to us were the compositions for purples and greens. Mixtures or overprinting transparent colors were noted in many prints from the 1740s on. In all analyzed purple regions, our results showed mixtures of safflower and dayflower (see figures 4 and 5). The presence of this mix-

Figure 6. ***The Heron Maiden (Sagi musume)*** **from the series** ***An Array of Dancing Girls of the Present Day,*** **(MFA 11.14364), 1793–94, designed by Kitagawa Utamaro I and published by Tsutaya Jūzaburō (Kōshodō).**

MINERAL SOURCE	JAPANESE NAME	COMMON ENGLISH NAMES	CHEMICAL FORMULA	COLOR
hematite	***benigara***	**red ocher**	Fe_2O_3	**red**
red lead	***tan, entan***	**red lead**	Pb_3O_4	**red**
vermilion	***shu, shin-sha***	**vermilion**	HgS	**red**
goethite	***odo***	**yellow ocher**	$FeO(OH)$	**yellow**
orpiment	***kio, sekio, shio***	**orpiment**	As_2S_3	**yellow**
azurite	***iwagunjo***	**azurite**	$Cu_3(CO_3)_2(OH)_2$	**blue**
synthetic	***gunjo***	**ultramarine**	$Na_{4\text{-}8}Al_6Si_6O_{24}S_{2\text{-}4}$	**blue**

Table 2: Common natural inorganic colorants used in Japanese woodblock prints.

ture throughout the history of color printing seems to indicate that the tone obtained by mixing dayflower blue and safflower was preferred over other possible mixtures of reds and blues (for example, indigo and madder) to yield purple. The green regions varied more often, with earlier prints showing overprinting of turmeric with dayflower (figure 3) while later prints showed a more vibrant green made by mixing orpiment and indigo (figures 4 and 5).

Two aspects of the results in this study seemed unusual. First, no examples of either gardenia (*Gardenia jasminoides*) or berberine colorants (e.g., *Berberis thunbergii, Coptis japonica, Phellodendron amurense*) were found in the analysis of 557 yellow spots in 213 prints. These plants, which generally grow in the highlands, have been described as common Chinese colorants that were used in the Japanese islands. The colorants were mentioned in the literature as being used for eighteenth century Japanese woodblock prints, but were not found on any prints analyzed in this preliminary study.

Second, madder was found on 142 red analysis locations in 90 out of the 213 prints (42%). While madder was available in Japan and was

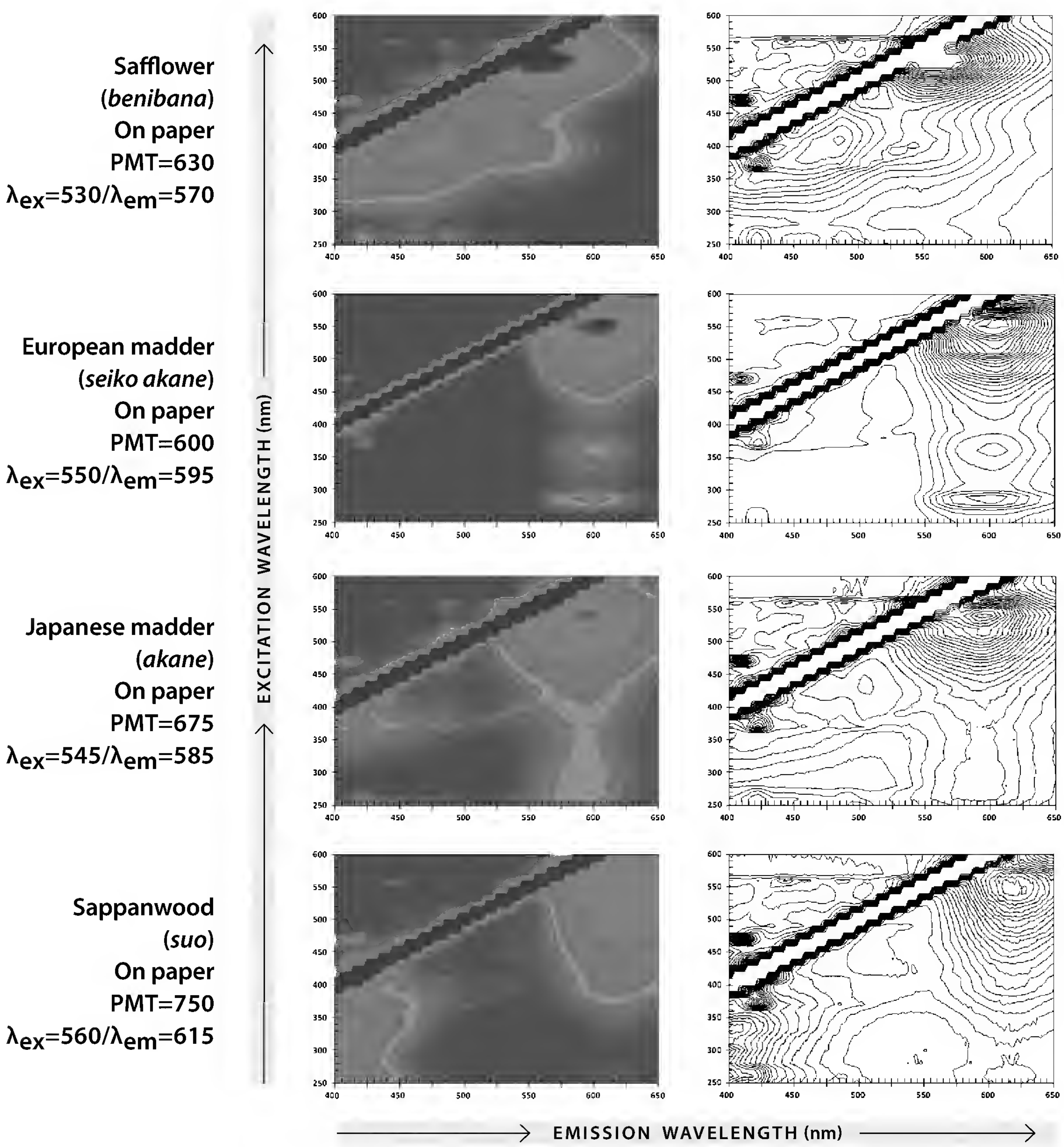

Table 3. Color and line contour plots for EEM fluorescent patterns of organic red Japanese colorants. Excitation and emission maxima are listed for the most intense spot.

Turmeric (*ukon*) On paper PMT=600 λ_{ex}=470/λ_{em}=525	
Silver grass (*kariyasu*) On paper PMT=700 λ_{ex}=455/λ_{em}=510	
Japanese pagoda tree (*enju*) On paper PMT=625 λ_{ex}=450/λ_{em}=510	
Gamboge (*shio*) On paper PMT=625 λ_{ex}= — /λ_{em}= —	
Amur corktree (*kihada*) On paper PMT=550 λ_{ex}=445/λ_{em}=525	
Gardenia (*kuchinasi*) On paper PMT=650 λ_{ex}=350/λ_{em}=450	

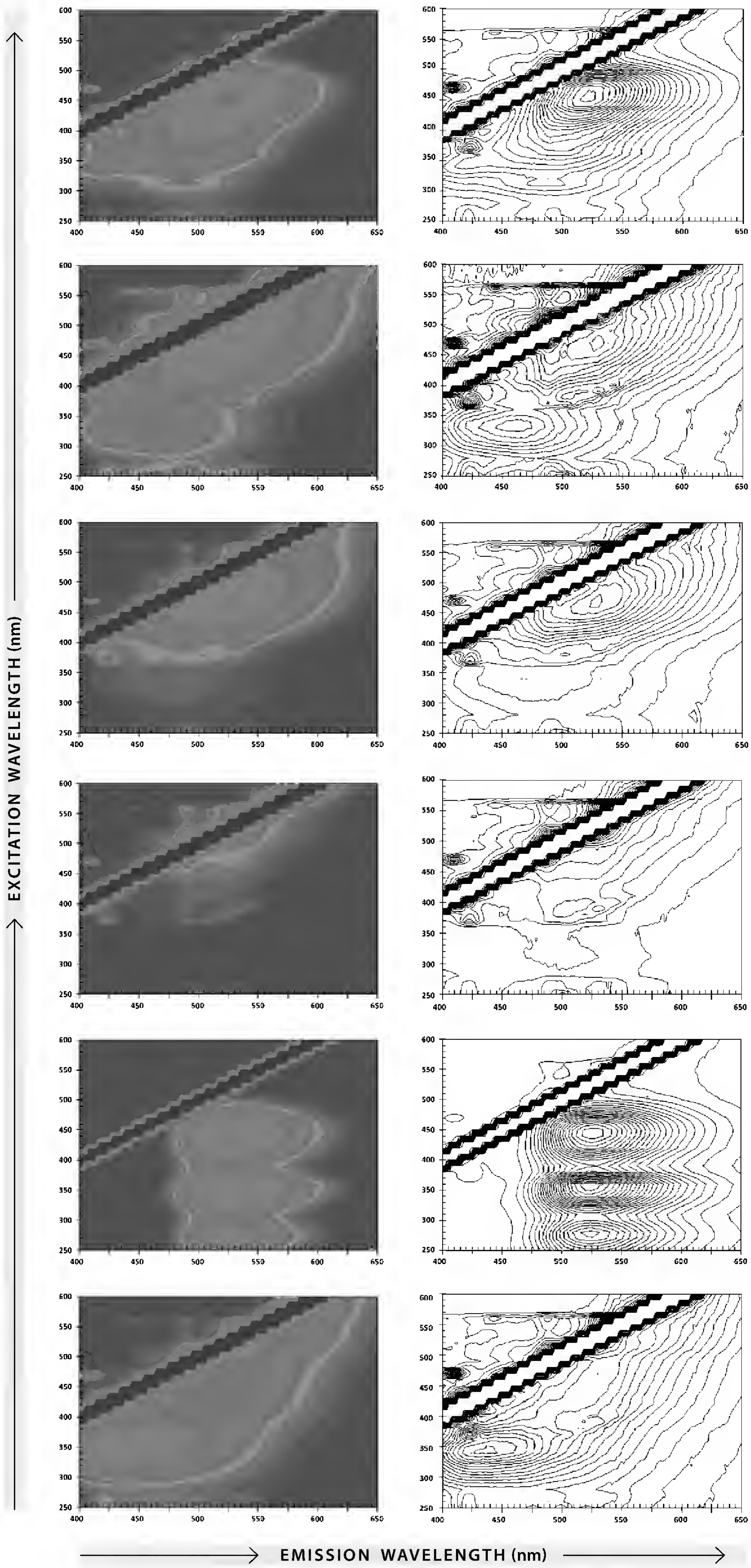

Table 4. Color and line contour plots for EEM fluorescent patterns of organic yellow Japanese colorants. Excitation and emission maxima are listed for the most intense spot.

Table 5. Summary of red and yellow organic and inorganic colorants found on 213 Japanese woodblock prints. The results are given as the percentages (%) of the EEM fluorescent pattern type, or element (as determined by XRF), attributed to the prints of each style of production. More than one type of each color was often used within the same print. Over 1,500 points were analyzed in this group of prints.

			PERCENT OF PRINTS CONTAINING THAT COLOR WITHIN THAT STYLE								
DATE RANGE	WOODBLOCK PRINT STYLE	NUMBER OF PRINTS	Turmeric	Flavonoid	Gamboge	Safflower	Madder	Sappanwood	Red lead (Pb)	Red ocher (Fe)	Orpiment (As)
1650s–1740s	Hand-colored prints, *Beni-e* and *Urushi-e*	16	0	75	75	63	19	6	12	19	0
1740s–1765	Limited-color prints, *Benizuri-e*	21	62	24	19	38	33	14	14	10	14
1766–1780	Full-color prints, *Nishiki-e:* First Period	80	36	28	23	78	39	26	25	20	50
1781–1801	Full-color prints, *Nishiki-e:* Golden Age	96	72	7	1	91	51	11	20	14	71

used prolifically as a textile colorant, it has not been previously mentioned as a possible colorant for printing. Madder may have been used as a substitution for more costly reds such as safflower (*benibana*) in order to keep the market price of an individual print affordable. With most of the print collection in the MFA, it is not always known whether the prints are first editions or later runs. Thus, there is always the possibility that madder was used for later editions, even though the date of the print is listed based on its initial production. Further work will be done to compare impressions and examine the paper fibers and formation methods to clarify the time periods of the madder use.

Additional Information on Specific Colorants

Safflower: *benibana*

The florets of safflower (*Carthamus tinctorius*) produce a wide range of colors from cherry red to pink (figure 7). Native to northern India and the Near East, this popular dye plant was widely cultivated throughout Asia and Europe by the end of the thirteenth century. It is a tender annual with spiny leaves and composite flower heads containing many yellow to orange disk florets. The florets are picked, then dried and crushed into a paste. The paste is washed with water to remove the non-lightfast yellow chromophores including several quinochalcones. The red colorant, primarily carthamin, is then extracted in an alkaline bath. The deepest reds are obtained through several initial washings to remove all of the water-soluble yellows.

Red regions containing safflower were usually seen as bright fluorescence during the preliminary examination of the prints with a hand-held ultraviolet (UV) light. Thus, it was no surprise that the EEM fluorescence technique provided a unique and definitive pattern for safflower, even when it was visually observed as a faded brown tone. In addition to the fluorescence for the red chromophore, the pattern often contained an additional peak for the yellow chromophore that was supposedly removed in the preparation of the red colorant but often needed several washings for complete elimination.

Printed examples of the safflower colorant can be seen in figures 1, 3, 4, and 5. In figure 1, the Kiyotada I hand-colored print from the *beni-e* period, safflower was found on the base of the umbrella and the flowers on the woman's kimono. Looking at the later Harunobu print from 1767–68 (figure 3), safflower was found on the purple robe of the kneeling child. In the 1788 print by Kiyonaga (figure 4), safflower was used for a pink collar, purple sleeve, and orange frame.

Madder: *akane* and *sieyo-akane*

The roots of madder plants (from *Rubia tinctorum, Rubia akane,* and many others) produce a deep true red color that was widely prized throughout the world (see figure 8). All madder family (Rubiaceae) plants give strong red dyes with the colorants concentrated in the parenchyma of the roots and stems, even though the plant and flowers do not exhibit any red colors. For processing, the roots were typically harvested in the autumn after a minimum of

FIGURE	MFA #	ARTIST/TITLE	ANALYSIS POINTS	ANALYSIS INTERPRETATION
1	11.13273	Torii Kiyotada I	Blank - womans face	—
			red on umbrella	Safflower
			pale robe man's chest	Flavonoid
			woman's robe near collar	Flavonoid
			orange corner man's robe	Gamboge
			skirt yellow and black	Brass flakes*
3	11.1903	Torii Kiyomitsu I	Blank - background	—
			green bell	Turmeric overprinted with dayflower**
			blue	Dayflower**
			yellow trim	Turmeric
			red foot	Madder
4	21.4463	Suzuki Harunobu	Blank- white snow	—
			yellow sky	Flavonoid
			green bush	Orpiment* mixed with indigo**
			red post	Sappanwood
			red ribbon	Sappanwood
			brown robe	Safflower mixed with dayflower**
			orange leaf on robe	Flavonoid mixed with sappanwood and safflower
5	11.13921	Torii Kiyonaga	Blank - face	—
			red ground cloth	Madder
			yellow pants on musician	Flavonoid
			green grass	Orpiment* mixed with indigo**
			green knee	Orpiment* mixed with indigo**
			pink collar on woman	Safflower
			pink shoulder on man	Safflower
			orange scroll border	Safflower mixed with turmeric
			purple cuff on man	Safflower mixed with dayflower**
			yellow at bottom	Turmeric
			yellow fence	Turmeric
6	11.14364	Kitagawa Utamaro I	Blank - face	—
			center yellow flower	Flavonoid
			green in hat	Flavonoid with dayflower**
			yellow ribbons	Flavonoid
			pink kimono	Safflower
			brown in hat	Safflower
			blue on kimono	Dayflower**

Table 6. Summary of the analytical results for four Japanese woodblock prints covering the range of eighteenth century printing styles. Identification of colorants was made by EEM fluorescence, XRF*, and FORS**.

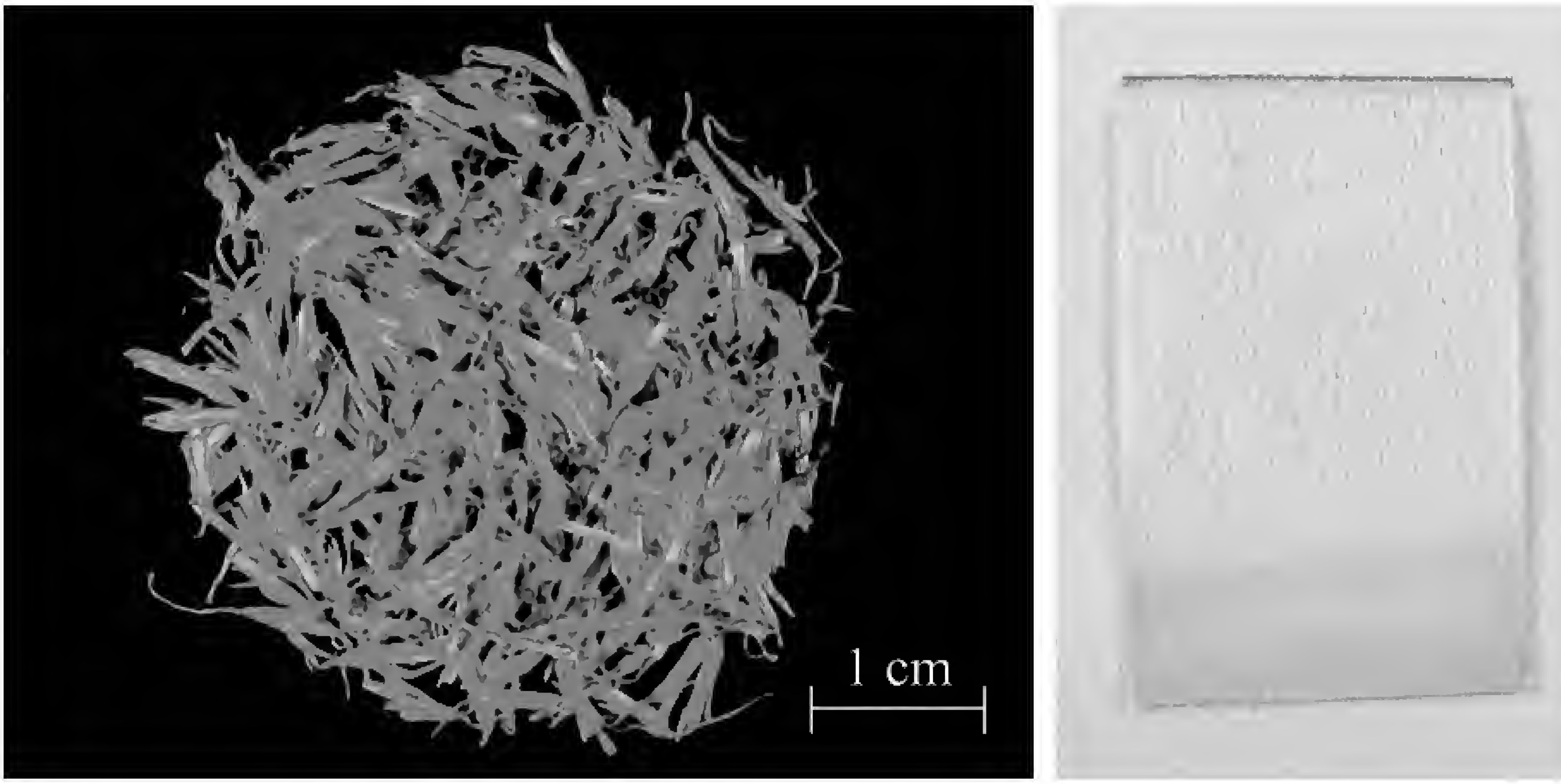

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Figure 7. Safflower (*Carthamus tinctorius*). Photomacrograph of dried florets for prepared dyes and an example of safflower dye on paper.

two years growth. The plants were marketed as whole dried roots rather than as a powder.

Madders, a general name applied to anthraquinone-containing dyes extracted from plants from various genera and species, often exhibit strong (orange) fluorescence in a work of art when examined under ultraviolet radiation. The strong fluorescence is usually stated to be associated with purpurin, a common anthraquinone found in many types of madder, including both *Rubia tinctorum* and *R. akane,* a plant native to Japan. It is not certain when *R. tinctorum* was first utilized in Japan, or from where it would have originated, but it does not appear to be possible to distinguish it from *Rubia akane* based on its EEM fluorescence pattern.

Printed examples of the intense red madder colorant can be seen in figures 3, 5, and 6. Figure 3, the Kiyomitsu I limited color print from 1762, has madder as the sole red colorant and it was used for the man's robe, face, and feet. Looking at the later print by Kiyonaga (figure 5), madder was used for the red cloth under the musicians. When it was found, the madder EEM pattern was very distinct and its color was a bright deep red. Madder was not found in secondary colors such as purple or orange in the prints examined for this study.

Red dyewood: *suo*

The insoluble red dye from sappanwood (*Caesalpinia sappan*) and other types of red dyewoods (sandalwood, barwood, narrawood, padauk, camwood, Brazilwood, etc.) were prepared as colorants by pounding chips of the heartwood into a paste mixed with a little oil (see figure 9). These were formed into cakes or bars for storage and sale. The red colorant was so popular in the seventeenth and eighteenth centuries that many of these species are now extinct or endangered. Its color was said to be orange-red, brownish-red, or cinnamon-like.

Using our references, the EEM spectra could easily distinguish the sappanwood fluorescence pattern from safflower and madder. However, the reference spectra for a few other types of red wood dyes, such as sandalwood and Brazilwood, produced similar but not identical fluorescence spectra. Thus, it was difficult, if not impossible, to differentiate between the various red dyewood sources.

In this study, the red dyewood fluorescence pattern was not often found, its use being limited to just a few artists and publishers. The print by Harunobu (figure 4) shows an example of the red dyewood. It was used for both the red and the orange regions, while the

purple colorant was found to contain safflower and dayflower.

Turmeric: *ukon*

Described as the most popular yellow colorant in the world, the rhizomes of turmeric (*Curcuma longa*) produce a bright yellow orange dye that is commonly used for food and textiles (see figure 10). Native to India, turmeric is now cultivated worldwide. Though a perennial herb, the plant is often completely harvested, then the roots are cooked, dried, and ground into a powder. Turmeric is a direct dye with high tinctorial strength that began its use as a fabric dye prior to the tenth century and is still used today as a curry seasoning.

Yellow regions containing turmeric usually were brightly fluorescent during the preliminary examination of the prints with a hand-held UV light. The dye produced a very clear, consistent fluorescence pattern, likely because of its single primary chromophore.

In this study, the printed examples that contain turmeric are figures 3 and 5. In the print by

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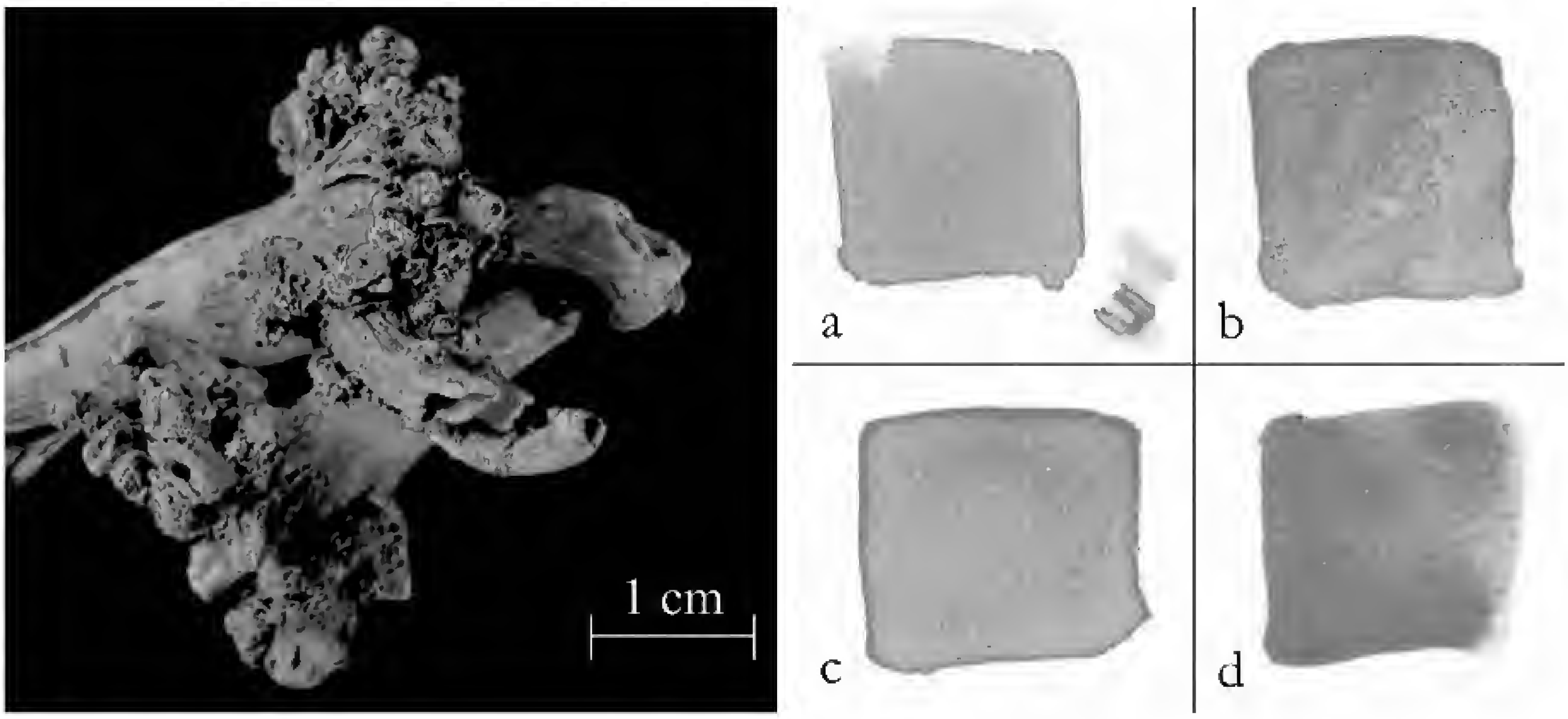

Figure 8. Photomacrograph of *Rubia tinctorum* dried roots for prepared dyes and examples of madder dyes on paper.

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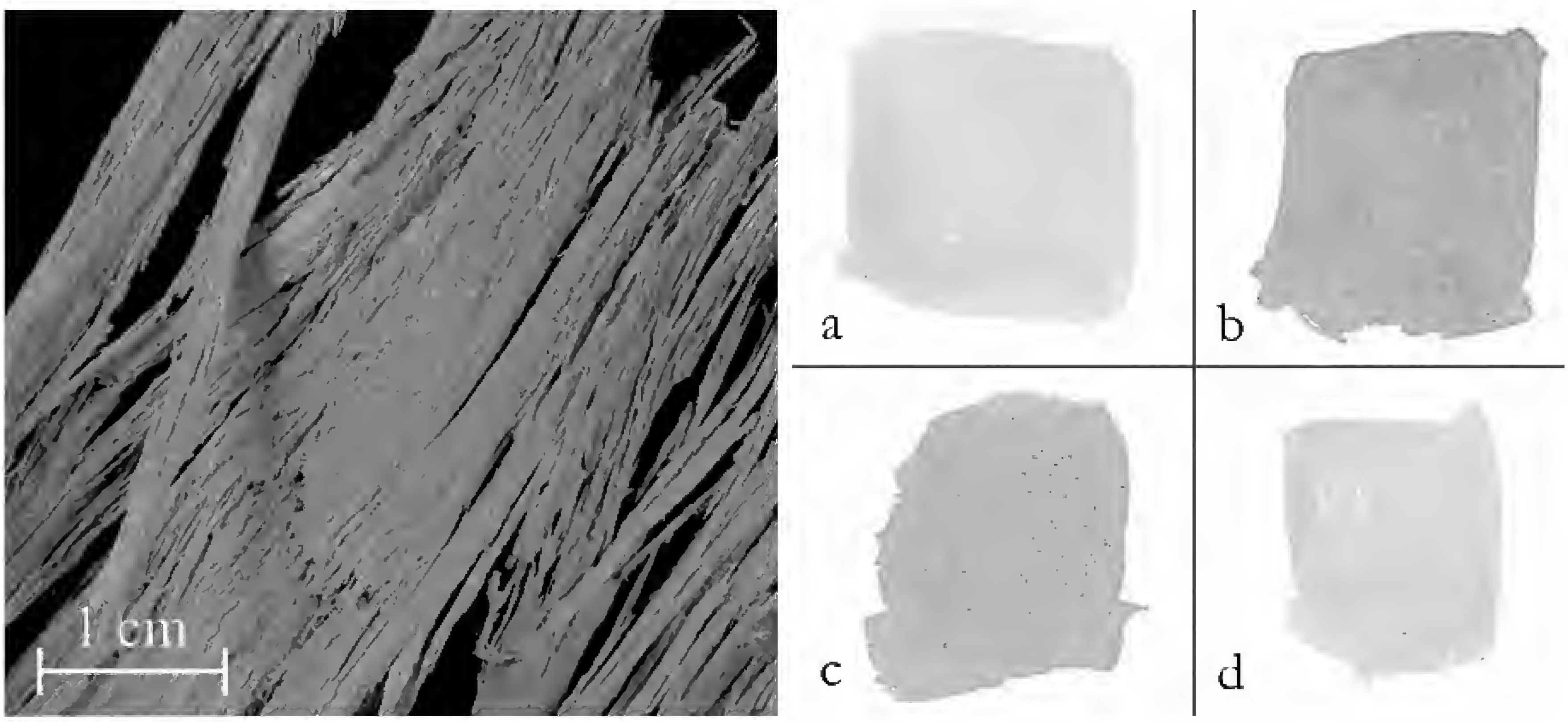

Figure 9. Sappanwood (*Caesalpinia sappan*). Photomacrograph of sappanwood and of paper dyed with sappanwood extract.

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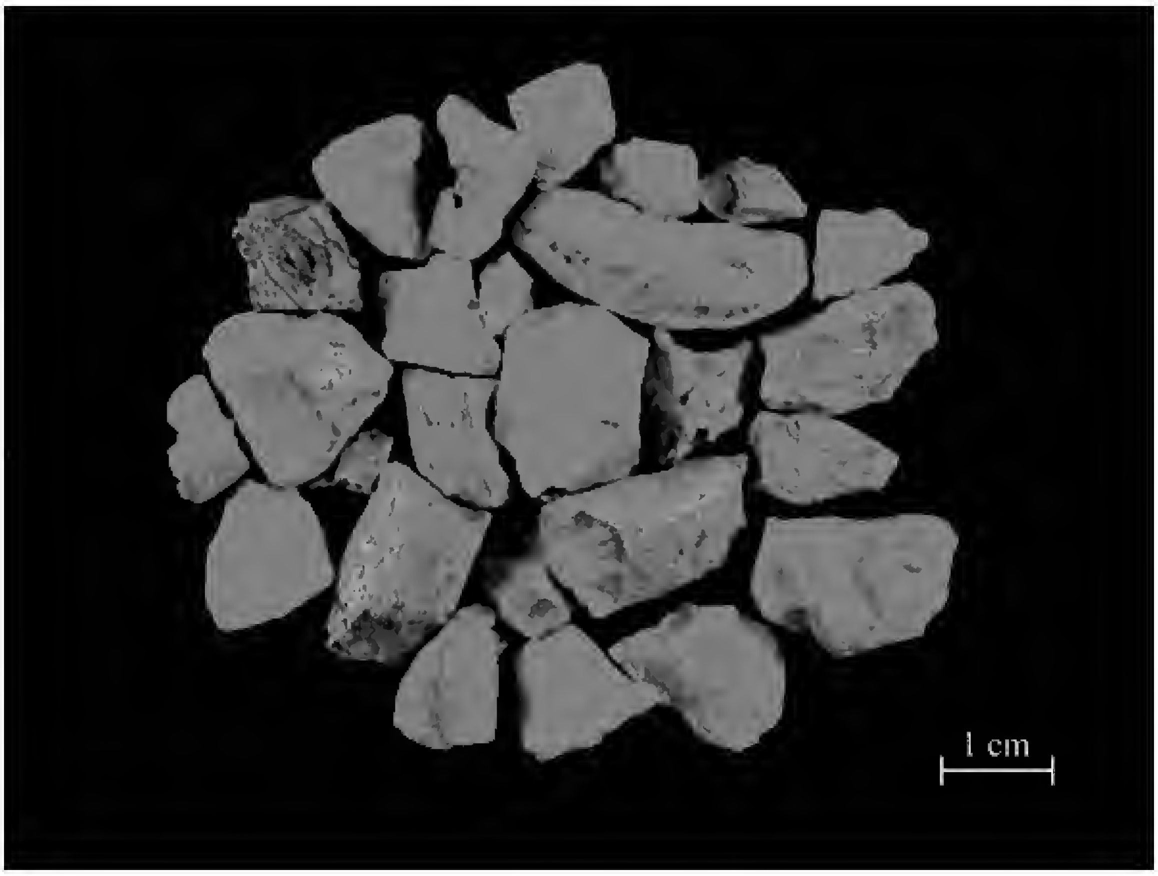

Figure 10. Turmeric (*Curcuma longa*). Photomacrograph of dried and cut rhizomes and an example of turmeric dye on paper.

Kiyomitsu I, turmeric is used as a clear, intense yellow for the trim as a contrast to the bright red. In the print by Kiyonaga, turmeric is used as a strong yellow background color. This colorant is fairly lightfast and retains its color better than the flavonoids.

Flavonoids—silver grass: *kariyasu;* Japanese pagoda tree: *enju;* Toringo crabapple: *zumi*

Flavonoids occur in most dye plants and their yellow colorants were discovered from the earliest times. While many colorants in this group are not lightfast, their abundance has resulted in their wide use. In Asia, the primary flavonoid-containing plants were the luteolin containing grasses, such as *Miscanthus tinctorius* (silver grass: *kariyasu*), that were cut each fall, then dried, and kept until the next spring for extraction. Other common Japanese dyeing plants include *Styphnolobium japonicum* (syn. *Sophora japonica;* Japanese pagoda tree: *enju,* see figure 11) and *Malus sieboldii* (Toringo crabapple: *zumi*).

Flavonoid-containing dyes tend to have numerous compounds. For fluorescence measurements, the emission positions were similar and tended to blend into a single elongated peak. This pattern tends to be weaker than the turmeric pattern and was often noted mixed in with the absorption pattern for the paper, thus making positive identification difficult. Additionally, it was difficult to make any consistent determination for the various types of flavonoid yellows. Since each contains similar compounds, but in different proportions, the excitation and emission maxima are similar, blending into an oblong mesa-type absorption area rather than a single peak.

In this set of analyzed woodblock prints, flavonoids tended to be a popular early colorant that later gave way to the use of turmeric and orpiment. One possible reason for the shift in yellow colorants is the poor light stability of most flavonoid yellows. The prints shown in figures 1, 4, 5 and 6 show examples of yellow flavonoid printed colors. Figure 6 was included as an example to show that even though it is difficult to distinguish between various flavonoid colors, this print does show two visually different yellow-colored regions that both produced slightly different fluorescence spectra even though both corresponded to flavonoids. It is possible that this print contains two types of flavonoid yellows, such as Japanese pagoda tree and Toringo crabapple. It is also possible that the print was exposed to uneven levels of light and that the yellows at the top of the print have deteriorated differently than those at the bottom.

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Figure 11. Japanese pagoda tree (*Styphnolobium japonicum*) flower buds and photomacrograph of paper dyed with pagoda tree buds.

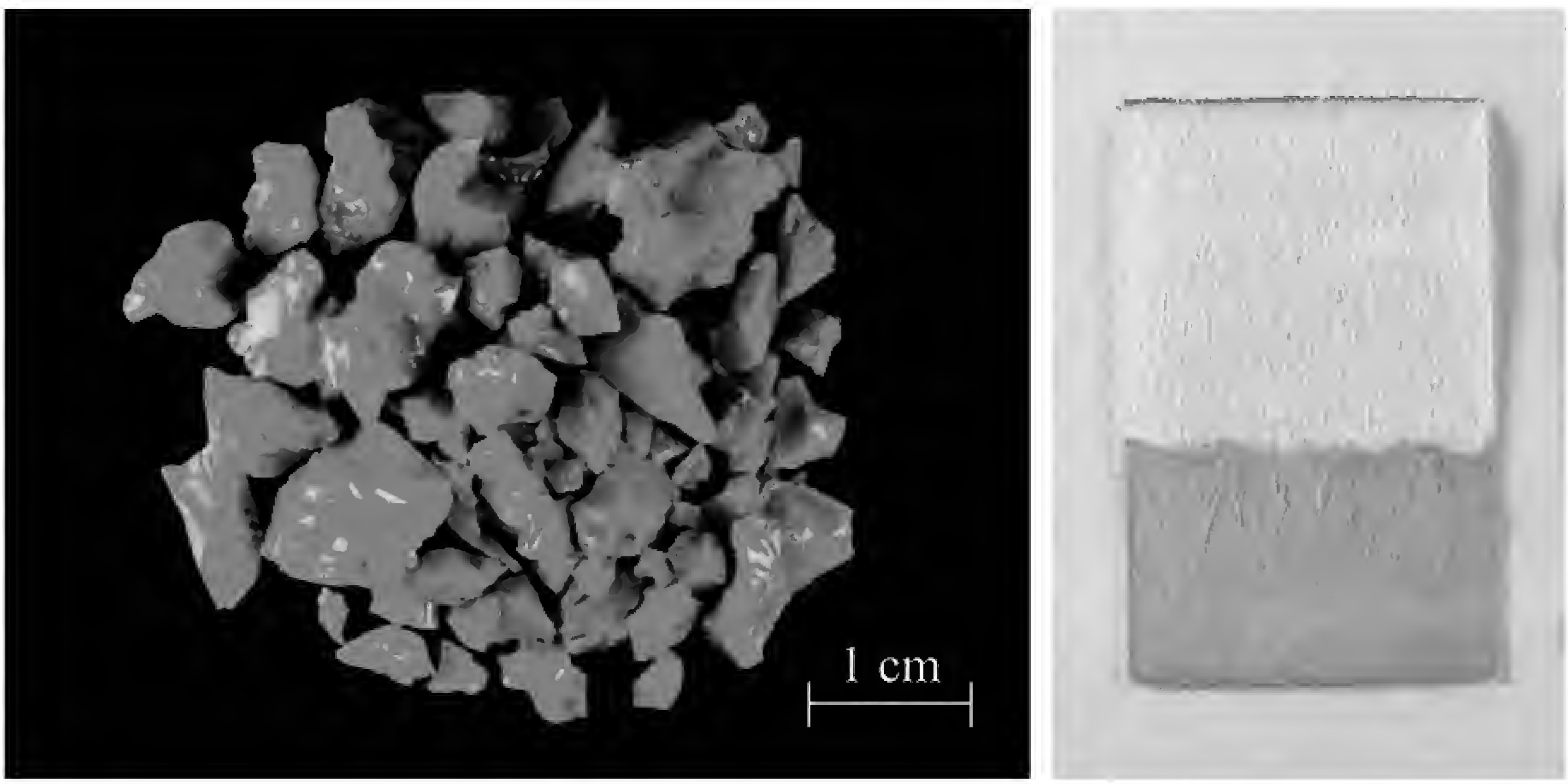

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Figure 12. Photomacrograph of *Garcinia hanburyi* (gamboge) resinous pieces from the Harvard Museum of Natural History and photomacrograph of paper dyed with gamboge.

Gamboge: *shio*

Gamboge is a golden yellow colorant that is extracted by tapping resin from various species of the evergreen *Garcinia* trees, most commonly *G. hanburyi* and *G. morella* native to southeast Asia and India (see figure 12). The trees must be at least ten years old before they are tapped. The resin is extracted by making spiral incisions in the bark, and by breaking off leaves and shoots and letting the milky yellow resinous gum drip out. The resulting latex is collected in hollow bamboo canes. After the resin is congealed, the bamboo is broken away and large rods of solidified resin remain. Gamboge is marketed as solid pieces or as a powder.

Visually, under a hand-held UV light, the yellow regions containing this colorant appeared dark, as if absorbing the fluorescence. The lack

of fluorescence was confirmed by the EEM fluorescence pattern produced for reference samples of gamboge. The pattern exhibited a complete absence of emission peaks; this also included an absence of the paper peaks indicating that the paper was covered with a blocking agent. Gamboge is the only known organic reference in the potential set of Japanese colorants that corresponds to this negative pattern. Thus, this is a unique material that visually appeared yellow, but without sampling, it could only be characterized by the absence of any measurable inorganic elements (e.g., Fe, As) by XRF along with the absence of any unique fluorescence pattern by EEM fluorescence.

Gamboge was most often found in the hand-colored, *beni-e,* prints and is illustrated in the corner of the warrior's robe (figure1), along with other non-analyzed points such as the kimono collars and the center frame of the umbrella.

Dayflower: *aigama; awobama*

Though rarely used elsewhere, dayflower (*Commelina communis*) blue was commonly used in Japan. Dayflower is an annual plant native throughout much of eastern Asia that bears one-day-blooming flowers featuring two large blue upper petals. The anthocyanin-containing juice extracted from the flowers was used by illustrators and printers for blue and green colors. Cloth or paper was dipped into the juice and dried; once needed the cloth or paper was dipped into water to extract the blue colorant (see figure 13).

The best analytical method for the identification of dayflower is fiber optic reflectance. An example of the difference in the FORS spectra for dayflower and indigo is shown in figure 14. As dayflower and indigo were the only two plant-based blues dyes used for woodblock prints, the FORS method could quickly and simply distinguish between the two materials.

Though dayflower was sometimes used by itself for blue areas (see figures 3 and 6), its poor lightfastness and its sensitivity to water were possible reasons that it was most often found used for greens and purples. Figures 3, 4, 5, and 6 show examples of the green and purple tones.

Indigo: *ai*

Indigoid dyes were used in Neolithic Europe, Pharaonic Egypt, and now in twenty-first century jeans (see figure 15). While the source plants provide slightly different hues, indigo

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KEITH LAWRENCE, MFA, BOSTON, HTTP://CAMEO.MFA.ORG/WIKI/FILE:DAYFLOWER_BLUE.JPG

Figure 13. Dayflower (*Commelina communis*) plant photo and photomacrograph of water soluble dayflower blue dried on paper.

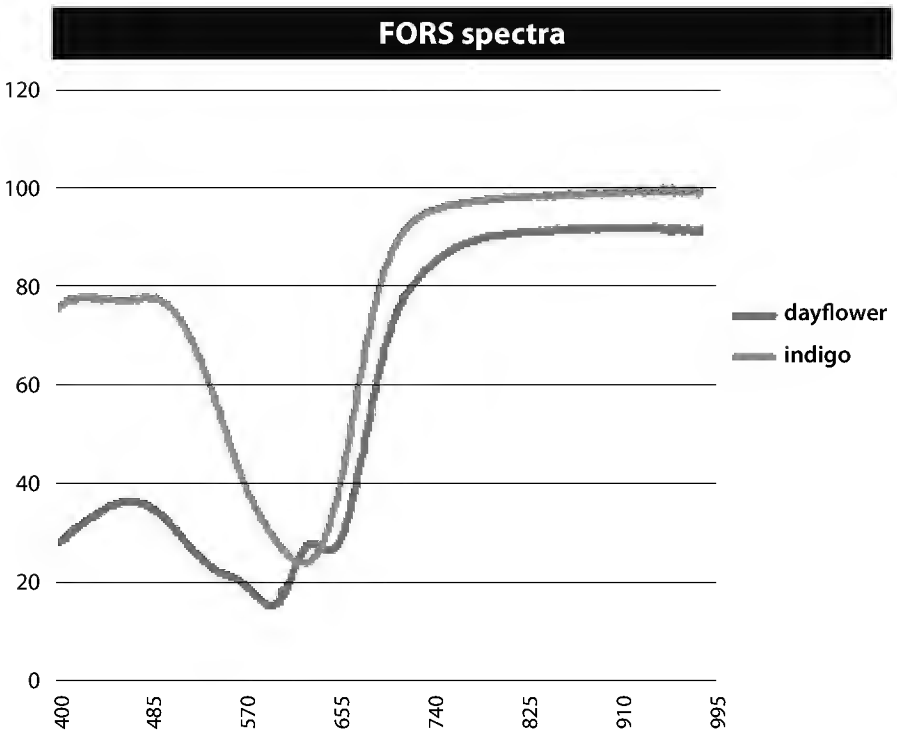


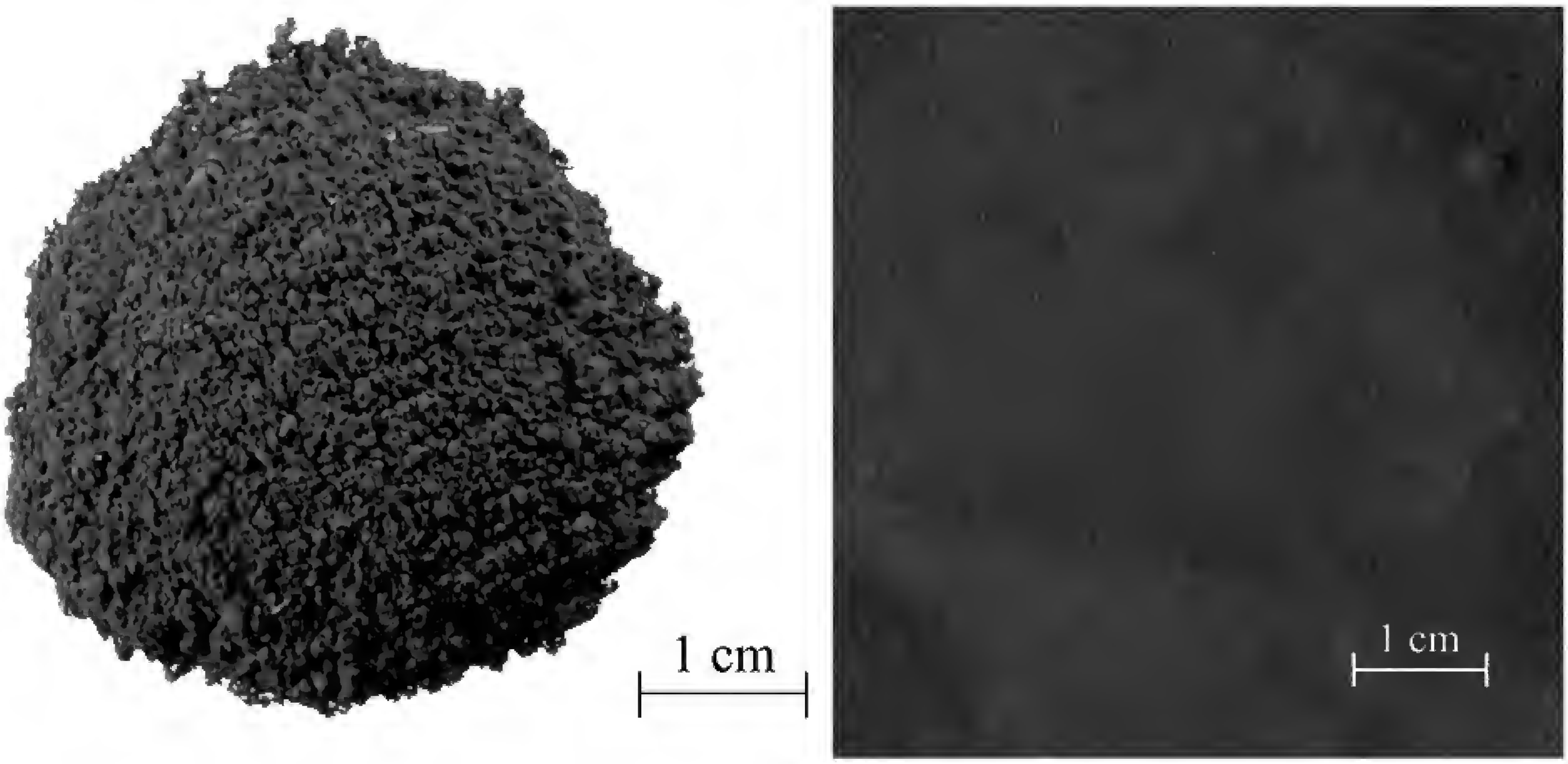
Figure 14. Overlay graph showing the Fiber Optic Reflectance (FORS) spectra for dayflower (*Commelina communis*) on paper versus indigo (*Indigofera tinctoria*) on paper.

has been regarded as the color of kings. Indigo producing plants, such as *Indigofera tinctoria* (a tropical shrub or subshrub), contain colorless glycocides that can be converted to the blue colored indigo on exposure to oxygen. To produce the dye, the fresh leaves are macerated in hot water, after which an alkali is added (such as lime) to ensure the colorant remains in a colorless soluble form. Once the colorant is extracted, it is either printed out or cast into cakes where the insoluble blue indigo precipitates as it reacts with oxygen from the air.

Of the prints selected for this article, indigo was found in figures 4 and 5 in the bright grass green colors. For both prints, orpiment, an inorganic yellow, was mixed with indigo to obtain the vivid, somewhat lightfast color.

Conclusion

The purpose of this paper is to provide specific information on the analysis and identification of natural colorants used in the production of Japanese woodblock prints. Three nondestructive analysis techniques were used so that no samples were removed from the prints. X-ray fluorescence (XRF) was used to determine the presence of any inorganic compounds, and fiber optic reflectance spectroscopy (FORS) was used to distinguish between indigo and dayflower in the blue, green, and purple regions. Additionally, methods were developed to successfully use a third technique, excitation-emission matrix (EEM), or 3-D, fluorescence spectroscopy, for the characterization of the red and yellow plant-based colorants.



KEITH LAWRENCE, MFA, BOSTON, HTTP://CAMEO.MFA.ORG/WIKI/INDIGO

Figure 15. Indigo (*Indigofera tinctoria*). Photomacrograph of powdered indigo dye and of paper dyed with indigo.

The MFA collection of Japanese woodblock prints is an ideal venue for the use of three combined techniques for the identification of the colorants because:

- The palette used for woodblock prints is limited.
- The colorants and substrates for the print were prepared with consistent, often documented, methods that had minimal variation.
- The prints are flat and the size of the prints, even within their mats, is less than 1 square meter.
- The speed for all three types of analysis is fast and allows for easy analysis of multiple locations.
- The MFA has an extensive set of over 50,000 Japanese woodblock prints and illustrated books that allows for extensive surveys of the materials within each time period, style, publisher, and artist.
- The knowledge obtained from the colorant identification will promote the understanding of the light stability for each print, and thus help preserve its vibrancy.

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Michele Derrick is the Schorr Family Associate Research Scientist, Joan Wright is the Bettina Burr Conservator in Asian Conservation, and Richard Newman is the Head of the Scientific Research Division, all at the Museum of Fine Arts, Boston.

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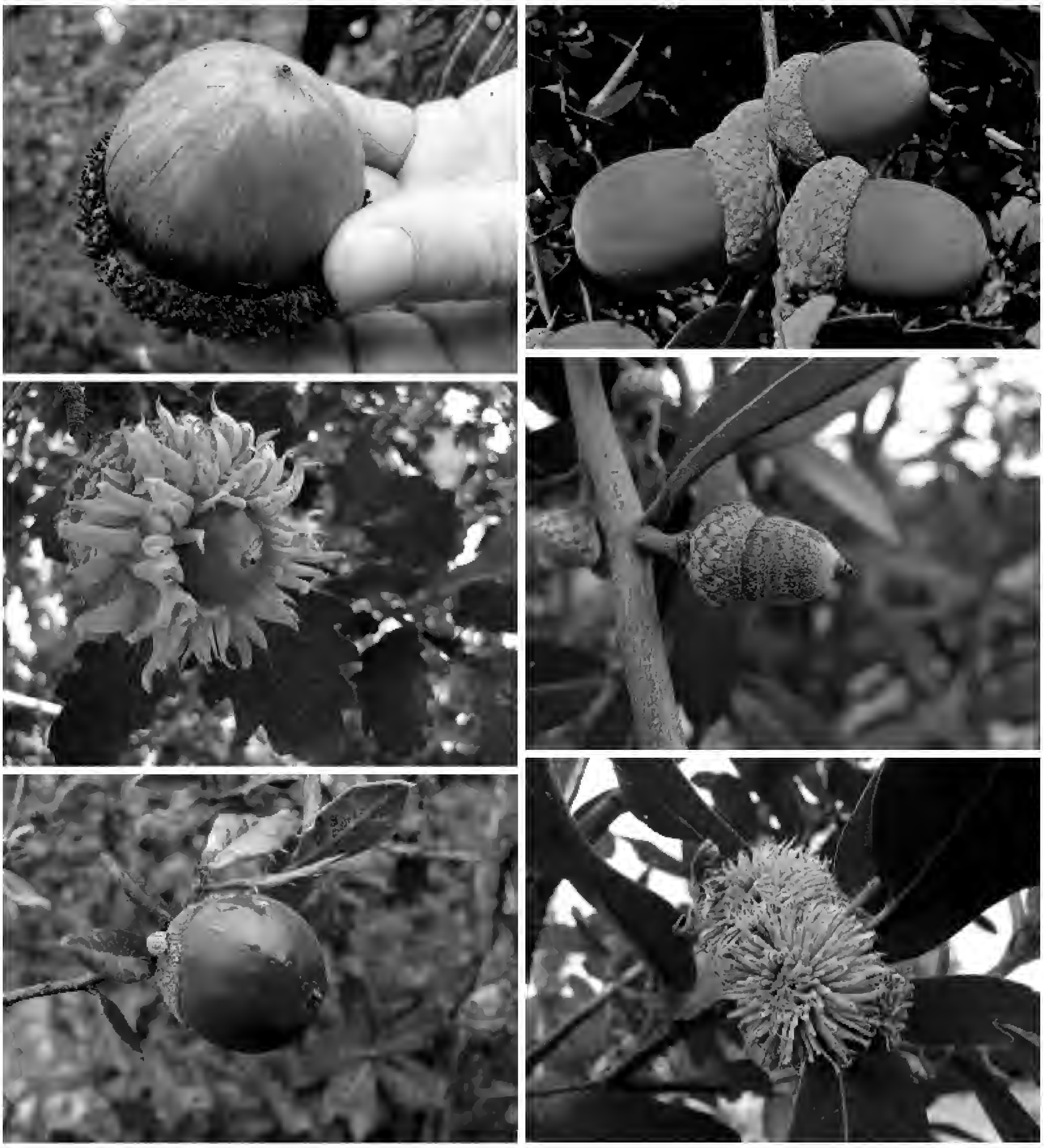
A Tour of the Oaks of the Arboretum des Pouyouleix

Béatrice Chassé

Oaks (*Quercus*) occupy every ecological niche in the Northern Hemisphere. The natural distribution of the genus only extends into the Southern Hemisphere in Indonesia where a few species can be found. In Europe there are 38 species, in Asia 156, while North and South America together harbor 236, for a worldwide total of 430. Visitors to the Arboretum des Pouyouleix are always surprised to learn that Mexico, with 150 (90 of which are endemic), is the country with the greatest number of species.

The diversity in number of species is paralleled by the morphological diversity of the



EIKE JABLONSKI

Oak (*Quercus*) acorns are diverse in size and form. Clockwise from upper left: *Q. insignis* (Mexico); *Q. chrysolepis* (USA); *Q. hypoleucoides* (USA); *Q. dolicholepis* (Asia); *Q. monimotricha* (Asia); *Q. macrolepis* (Europe)

Leaves of the Mexican oak species *Q. urbanii* are bright crimson when newly emerged.

The handsome form and foliage of loquat oak (*Q. rysophylla*) has made it a favorite of plant connoisseurs.

***Quercus viminea,* native to Mexico, has elegant, glossy foliage.**

***Quercus cornelius-mulleri* is a scrub oak native to California and Baja California. It was named for noted botanist and ecologist Cornelius H. Muller (1909–1997).**

leaves, as reflected by some of their common names: maple-leafed oak, loquat oak, chestnut oak, bamboo oak, holly oak, willow oak, myrtle-leafed oak, laurel oak, and so on. The diversity of acorn morphology is as surprising and wonderful as the diversity of leaf morphology and habit.

Since the oak collection of the Arboretum des Pouyouleix is planted geographically, I'd like to introduce *Arnoldia* readers to some of the most interesting oaks here by taking a tour through the collection and providing some details and personal memories of collecting trips around the world.

MEXICO

Though I find it impossible to decide which is my single favorite oak, without a doubt my favorite oaks come from Mexico. Beyond their extraordinary diversity and beauty, my fondness results from the facts that, one, many of my best oak adventures with both the plants and the people interested in those plants are linked to that country, and two, that all of the Mexican oaks, with a few exceptions, grow so well here at the Arboretum des Pouyouleix. To be sure, there are beautiful and interesting oaks all over the world but for me nothing quite so extraordinary as a young leaf of *Q. urbanii,* as unbelievable as the acorn of *Q. insignis,* as elegant as *Q. viminea,* as majestic as *Q. rysophylla*—the list of superlatives is endless.

Although it might be an exaggeration to say that *Q. rysophylla,* loquat oak, is everybody's favorite tree, it does have an impressive list of admirers. It was selected as "Tree of the Year" in 2015 by the International Dendrology Society (IDS), and botanist Allen Coombes, writing for the IDS Yearbook, described the young coppery leaves as quite unlike anything he had ever seen before when he first saw the tree in 1980 (Coombes 2016). John Grimshaw, in *New Trees: Recent Introductions to Cultivation* (Grimshaw and Bayton 2009), wrote, "Of all the trees in this book, *Quercus rysophylla* is the one that has made the greatest impression on me, wherever it has been seen, and if only one 'new tree' were to be grown, this should perhaps be it." In 1978, Lynn Lowery, horticulturist and plant collector from Texas, regarded this species as a VIP (very important plant) (Creech 2016) and John Fairey, another noted plant collector and nurseryman from Texas, said "If I had to have one oak, it would be *rysophylla.*" (Raver 2012). Our first *Q. rysophylla* was grown from acorns collected in Chipinque Park in Nuevo Léon, Mexico, and planted here in 2004, measuring 23 centimeters (9 inches) tall. Today it measures nearly 9 meters (30 feet). The lovely dark green, thick and shiny, nearly sessile leaves are densely clustered and, when young, vary in color from bronze to red. We have planted six other trees of this species, which have grown even faster.

"9,490 Kilometers Across Mexico" (Chassé 2011), an account of my second trip to Mexico, in 2010, could just as well have been titled "In the Footsteps of Cornelius H. Muller." Perhaps *Quercus mulleri* and *Q. cornelius-mulleri* are the most immediately visible traces in the oak world of this incredible botanist who was still actively involved, in his mid-eighties, in preparing the *Quercus* section of the *Flora of North America* with botanist Kevin Nixon. Muller was indefatigable in the field and a large part of my itinerary in 2010 was based on the detailed location descriptions of the oak discoveries he made during his adventures in northern Mexico. These included *Q. × basaseachicensis* near the Basaseachic Falls in Chihuahua, *Q. flocculenta* halfway up the Cerro Potosí in Nuevo Léon, *Q. edwardsiae* in Chipinque, Nuevo Léon, but above all, in Chihuahua, *Q. deliquescens,* which provides a story that started in the town of Delicias ("delight" in Spanish) and ended in Milagro ("a miracle").

Muller wrote, "Recent heavy concentration of collecting efforts in the Chihuahuan Desert region of Mexico ... have yielded much new information on the flora and its distribution. Among the novelties is a striking species of *Quercus* here described as new" (Muller 1979). The text continues with a precise description of how to approach the location (most useful even when one has GPS coordinates) and so off we went, leaving Delicias for the town of Julimes to get to the Sierra del Roque "... as approached from Minas Las Playas via Rancho El Saucito." After several hours of very difficult and slow driving through the Chihuahuan Desert,

The Arboretum des Pouyouleix, National Oak Collection (France)

How does one become an oak nut? Initially, my motivation was simply to create a botanic garden. But while my companion and I drove around southwestern France in search of suitable land, we kept noticing a majestic tree that dominated the landscape—it was *Quercus robur*. Though perhaps best known as pedunculate or English oak, it is such a common tree in northern Europe that it has dozens of common names in many languages. This inspired us to make oaks the focus of our future garden.

The Arboretum des Pouyouleix is located in the north of the Aquitaine region of France, in the department of the Dordogne, roughly 150 kilometers (93 miles) north of the city of Bordeaux and 200 kilometers (124 miles) from the western coast of France. The topography is quite variable, which provides planting sites with differences in soil composition and structure, drainage, exposure (to both wind and sun), and temperatures. Although we are theoretically in USDA Hardiness Zone 8b (average annual minimum temperature -9.4 to -6.7°C [15 to 20°F]), we rarely experience winter temperatures lower than -4°C (24.8°F), and summer highs are quite often in the mid 20s to 30°C (77 to 86°F). The average annual rainfall (for the past 11 years) is 917 millimeters (36.1 inches).

We decided to create the collection with plants raised from seeds, and preferably from wild-collected seeds in order to reduce (though not entirely eliminate) the possibility of hybridization. A propitious encounter in 2005 with several European oak enthusiasts from the International Oak Society paved the way for a series of collecting trips that have taken me across North America, Mexico, Vietnam, and Taiwan, collecting dozens of species including several new to cultivation in Europe.

The Arboretum des Pouyouleix now holds a little over 300 *Quercus* taxa (including 38 species on the IUCN Red List) and is certified as a National Collection for the genus in France. In addition, the Arboretum has about 600 taxa in a variety of other genera. The table below shows the growth rate of seven *Quercus* species at the Arboretum des Pouyouleix.

NAME	DATE PLANTED AND HEIGHT (m)		HEIGHT (m) 2015	AVERAGE ANNUAL GROWTH
Q. imbricaria[1]	12/2003	2.00	11.00	0.75
Q. saltillensis[2]	11/2011	0.09	3.50	0.90
Q. rysophylla[2]	11/2004	0.23	8.00	0.70
Q. dentata[3]	11/2004	0.87	6.00	0.50
Q. mexicana[2]	06/2012	0.40	5.00	1.50
Q. myrtifolia[1]	03/2008	0.11	3.50	0.50
Q. hintoniorum[2]	03/2007	0.10	4.50	0.60

Native to: [1]North America; [2]Mexico; [3]Asia

The Arboretum des Pouyouleix has varied topography that provides ideal sites for many oak species.

and, according to Mr. Muller's coordinates, just a hop, skip, and a jump from *Q. deliquescens,* we found ourselves confronted with a difficult choice: there before us, for as far as the eye could see in either direction, stretched a very tall barbed-wire fence. To go or not to go over the fence? What would you have done?

Driving back to civilization, we realized that we had started off without thinking to bring any food with us, although we did fortunately have enough to drink. So it was a miracle indeed, that the first town we came to, after several more hours of driving, had a small restaurant named ... El Milagro! But, truth to tell, the real miracle was that we were luckier than Mr. Muller who ends his description of the species with "... acorns unknown." This species is considered vulnerable by the International Union for Conservation of Nature (IUCN).

***Quercus deliquescens* is a rare oak species native to Chihuahua, Mexico.**

The area devoted to Mexico is the largest part of the Arboretum des Pouyouleix and comprises

Abundant male flowers are seen on the Mexican species *Q. hintoniorum*.

the greatest number of taxa. Many delightful oaks rare in cultivation can be found here: *Q. macvaughii; Q. miquihuanensis,* an endangered species; *Q. hintoniorum,* listed as vulnerable; *Q. crassifolia; Q. furfuraceae,* listed as likely endangered; and *Q. liebmannii,* to name but a few.

ASIA

Current phylogenetic understanding of the genus *Quercus* is that it is composed of eight lineages or groups. The group known as the ring-cupped oaks (section *Cyclobalanopsis*) is only found in Asia. Not all of the oaks that grow in Asia belong to this group—some of them belong to the white oak (section *Quercus*) lineage, which is ubiquitous throughout the natural distribution. Hands down, the ring-cupped oaks would win first prize in a contest for the most un-oak-like plants (at least for Western eyes), just as they would also win the contest for the group whose members are the hardest to distinguish from one another. Come to think of it, the seeds of at least two species, *Q. macrocalyx* (China, Southeast Asia) and *Q. pachyloma* (Southern China, Taiwan), would probably also win first prize in an acorn beauty contest. These two species, collected in Vietnam and Taiwan, respectively, are still in the nursery, perhaps to be planted this year.

Quercus myrsinifolia (China, Japan, Southeast Asia) and *Q. glauca* (China, Japan, Southeast Asia, Afghanistan, Bhutan, Nepal, Sikkim, India) are the two most common oaks from this group found in collections in Europe, the former having been introduced to cultivation in 1854 and the latter in 1804. We have several trees of both of these species that grow well. *Q. myrsinifolia* makes a prettier tree here, whereas *Q. glauca* tends to be bushy. This group of oaks is not very well represented in American arboreta. Of the 20 gardens in the Plant Collections Network (PCN) *Quercus* Multisite Collection, the University of Washington Botanic Garden has four, Bartlett Tree Research Lab (North Carolina) has five, and the Scott Arboretum (Pennsylvania), the University of California–Davis Arboretum, and the Morris Arboretum (Pennsylvania) each has one. Though not part of the Multisite Collection, the Aiken Citywide Arboretum (South Carolina) also has four.

My two favorite ring-cupped oaks growing here are *Q. salicina* (Japan, maybe Taiwan) and *Q. gilva* (Japan, Southern China, Taiwan, Vietnam). *Quercus salicina* is just a perfect, graceful tree. The leaves, evergreen (as with all *Cyclobalanopsis*), are elegantly elongated with a twist at the end. It will produce new leaves at various times from spring until early autumn, coloring the tree to different degrees in a beautiful deep burgundy red that fades to pink and finally to green. Of all our evergreen species it is one of the few that suffered absolutely no damage during a horrific 15-day cold spell in February 2012 with temperatures at night dropping to -18°C (-0.4°F), and daytime temperatures never above -8°C (17.6°F). *Quercus gilva* is one of the more easily recognizable *Cyclobalanopsis* in part because its leaves are characteristically widest in the middle but especially because the new leaves and shoots are distinctly yellow with a soft tomentum, giving it a unique ornamental quality

The Arboretum's Asia section also has many Asian oaks that are in sections other than *Cyclobalanopsis: Q. dentata,* with its huge, leathery leaves and sculptured bark; *Q. spinosa,* a very rare oak in cultivation; and *Q. semecarpifolia,* which holds, along with *Q. guyavifolia* and *Q. monimotricha,* the oak record for high-

CHARLES SNYERS D'ATTENHOVEN

Asian oak species *Q. macrocalyx* (left, photographed in Vietnam) and *Q. pachyloma* (right, photographed in Taiwan) have fabulous acorns.

Asian evergreen oak species *Q. salicina* (left) and *Q. gilva* (right) have handsome foliage.

altitude living (up to 4,000 meters [13,123 feet] for the first two and 4,600 meters [15,092 feet] for the latter).

Our expedition to Vietnam in 2013, though not entirely satisfactory in terms of the number of oaks found, was most interesting in what it revealed about the presence of certain oaks hitherto unreported in northern Vietnam (Chassé 2014). Much remains to be learned about the status of the oaks of Vietnam, indeed, about the forest communities in general, since during the second half of the twentieth century war, forest fires, slash and burn agriculture, encroachment for industrial purposes, and other forms of anthropic pressure have reduced forestland in Vietnam from 43% of the country's surface area in 1940 to 17% by the late 1970s (Bien 2001).

Daimyo oak (*Quercus dentata*), native to Japan, Korea, and China, bears enormous leaves.

EUROPE

Oak species diversity in Europe is not very high but there is interesting morphological diversity within the species present, and a few of them can indeed become most spectacular trees with truly impressive lifespans, especially *Q. robur,* pedunculate or English oak. This species also has the honor of being the first oak to have had its genome entirely sequenced (Plomion et al. 2015), a milestone for research into the evolutionary history of the genus. From an aesthetic point of view, the problem with quite a few European oaks is that they are moderately to severely affected by many diseases (powdery mildew, rusts, etc.) that, although not lethal, make the trees rather unattractive fairly quickly after the appearance of new foliage in spring.

Quercus alnifolia, endemic to Cyprus, is one of my favorites with its golden yellow to orange tomentum on the underside of the round and shiny evergreen leaves and its fabulously elegant acorns. It is a large shrub or small tree (6 to 9 meters [20 to 30 feet]) and as such makes a wonderful addition to any small or medium-sized garden. *Q. frainetto* (Balkans, Bulgaria, Greece, Hungary, Italy, Romania, and Turkey) is another very special European oak, the deep sinuses of the leaves giving a delicate lacelike aspect to the silhouette. This species is also less prone to the above-mentioned afflictions.

But my vote for the prettiest of all European oaks would be *Q. macrolepis.* Found across southeastern Europe from the Balkans to the Aegean Sea, Italy, and Turkey, it can be a shrubby tree of 5 meters (16 feet) or attain grand heights of 25 meters (82 feet) or more. The very striking silvery, grayish white color of the new leaves makes it a true eye-catcher on sunny spring days. And then of course, there is the acorn: one of the most fabulous of the genus (see page 29). I think that part of my enchantment with this species comes not only from its beauty but also from the importance of these acorns in human history, both in the leather-tanning industry for more than four hundred years (Mayer Maroulis 2014) and as a food source for probably much longer than that (Chassé 2016).


EIKE JABLONSKI


CHARLES SNYERS D'ATTENHOVEN

Interesting European oak species include (top to bottom) *Q. alnifolia* (photographed in Cyprus), *Q. frainetto* (photographed at Wisley, United Kingdom), and *Q. macrolepis.*

NORTH AMERICA

New foliage and flower buds of *Q. palmeri,* a shrubby oak native to California, Arizona, New Mexico, and Baja California.

We move now into the North American section. A dry, rocky, poor-soil area in this part of the Arboretum has proven to be an ideal place to plant many oaks from the southern (both east and west) United States. Generally, these oaks are accustomed to some level of environmental stress such as little rain, few nutrients, or harsh sun exposure. They are healthy plants here in France, many of them fruiting after only a few years, but tend to be slow growers. Four specimens of my favorite one, *Q. palmeri,* raised from seed collected in 2007 in Riverside County, California, were planted here in 2008, each measuring about 8 centimeters tall. Today they are all about 1 meter tall (trees of this shrubby species are generally not more than 3 meters tall at maturity). The emblematic southern live oak (*Q. virginiana*), one of the most magnificent oaks of the southern United States, with its wide-spreading branches that are often dripping with Spanish moss in its natural habitat from Texas to Florida and northward to Virginia, does very well here, as do *Q. chapmanii,* which is also from the southeast, *Q. toumeyi* from Arizona, and *Q. engelmannii* from California (listed as vulnerable on the IUCN Red List).

Nearby is an area with deep, rich soil that we call "la Grande Prairie." It was the first part of the Arboretum to be planted, on December 7, 2003, with the help of many neighbors and friends. We planted nearly 300 trees, most of them here. Under a bright blue sunny sky we toiled away and, when we were finished, it began to rain. Though I am not at all a superstitious person, one has to admit that this was a good omen! In this part of the Arboretum can be found most of the common North American oaks. I use the word "common" in the sense that they have been in cultivation for a long time—some for more than two centuries—and can be easily obtained through the nursery trade, but they are nonetheless extraordinary trees. Northern pin oak (*Q. ellipsoidalis*), scarlet oak (*Q. coccinea*), Shumard oak (*Q. shumardii*), willow oak (*Q. phellos*), shingle oak (*Q. imbricaria*), northern red oak (*Q. rubra*), water oak (*Q. nigra*), swamp white oak (*Q. bicolor*), white oak (*Q. alba*), black oak (*Q. velutina*), bur oak (*Q. macrocarpa*), pin oak (*Q. palustris*), and many, many others are thriving here, reaching heights (for the fastest growers) of more than 15 meters (49 feet) since 2003. This area of the Arboretum is the best seat in the house come autumn as this mix of trees produces a vertiginous scale of color from yellow to orange to pink to red, set off by the surrounding chestnut-oak woodland that gives a magnificent backdrop of yellow and orangish brown.

It is in this part of the Arboretum that I am occasionally struck by the awesome temporal dimension of what it means to plant trees. In just thirteen years, these trees, destined to live several hundred years, have created a world of their own but of which I am a part. And though, regrettably, I will not live for several hundred years, it is as though my trees have created a bridge through time for me. This exceptional experience was magnified a hundred-fold when I visited the Arnold Arboretum in October 2015 because, of course, many of the trees there (oaks and other) have been planted for decades, some for more than a century. They are thus at once a bridge through time past and time future. For those of us who plant trees, the Arnold is truly a unique voyage, and without a doubt the most magnificent arboretum I have ever visited.

Many of the North American oaks display bright autumn leaf color. From right to left, going down the hill, *Q. palustris, Q. coccinea,* and *Q. muehlenbergii.*

On either side of "la Grande Prairie," moderately steep slopes with rather poor soil have provided well-drained, sheltered areas for the planting of more fragile species from North America. I have come to the conclusion that, although cold is obviously a limiting factor to plant survival, heavy, rich soil and too much water in the fall and winter are equally serious handicaps for a great many oaks. On these slopes, many oaks that probably shouldn't enjoy being here because of the cold are very happy indeed: *Q. myrtifolia* (fruiting this year) and *Q. inopina* from Florida, and *Q. invaginata* and *Q. insignis* from Mexico, to name but a few.

CONCLUSION

As we turn to walk back up "la Grande Prairie" I should just point out a fine specimen of *Q. tomentella,* an oak endemic to the Channel Islands (off the coast of southern California), considered to be vulnerable by the IUCN. Near the house and other buildings, at the top of "la Grande Prairie," many oaks, irrespective of geographic origin but that share the characteristic of being rather short and liking fairly poor soil, have been planted, including *Q. vacciniifolia* from California, *Q. pumila* from Georgia, *Q. minima* from South Carolina, and *Q. guyavifolia* and *Q. monimotricha* from China.

Many, many seeds have been—and are being—sown here at the Arboretum des Pouyouleix. The seeds collected during the trips I've mentioned in this article, and plants raised from them, have been shared with different gardens and arboreta in France and around the world (Argentina, Belgium, China, the Czech Republic, Germany, the Netherlands, Spain, Taiwan, the United Kingdom, the United

States of America, and Uruguay). A few years ago, there were almost exclusively Mexican and North American species in our nursery: these days, almost only Asian species, with many wonderfully exciting plants from Vietnam, China, and Taiwan, including some that have yet to be identified.

In these times of ecological crisis, I should like to end this little journey with a sincere homage to plant collectors and plant propagators past and present. Identifying fragile zones and endangered species is surely a useful exercise, but is it not necessary, if we want to save those species, to have knowledge about their cultivation? In Europe, very nearly the only arboreta that are growing many endangered oak taxa, or, less dramatically, the more recent introductions, are the private ones. These collections are a valuable resource for conservation efforts and for building awareness about the beauty and the diversity of our planet.

Runner oak (*Q. pumila*) is a shrubby, spreading oak native to the Coastal Plain of the southeastern United States.

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One of a Kind: *Pinus monophylla*

Nancy Rose

I've led many plant identification classes and walks in my career as a horticulturist. When it comes to pines (*Pinus*), I've taught that pines always carry multiple needles grouped in fascicles (bundles), which readily differentiates them from spruces (*Picea*) and firs (*Abies*) (the other common "tall, pointy evergreens"), which both bear single needles. To then identify individual pine species, the first step is to see if the bundles hold two, three, or five needles. That's still good advice about 99 percent of the time, but when I came to the Arnold Arboretum I discovered a notable exception to those rules: *Pinus monophylla,* the single-leaf pine.

Pinus monophylla is a member of the pine family (Pinaceae) and is one of 114 species in the genus *Pinus.* It is part of subsection *Cembroides,* a group of pine species native to the western United States and Mexico commonly known as pinyons, or piñons (*P. monophylla* is also known as single-leaf pinyon). The pinyons have thin-shelled, edible seeds; *P. monophylla* and *P. edulis,* Colorado or two-needle pinyon, have especially large (1/2 inch [1.3 centimeters] long), high-fat-content seeds that have long been harvested and used as an important food source by indigenous peoples.

Single-leaf pine grows about 15 to 30 feet (4.6 to 9.1 meters) tall and has a pyramidal form when young, becoming more irregular and spreading with age. As the common name indicates, this pine bears single needles on its stems, the only pine species to do so. Individual needles are thick, sharp-tipped, and bluish green with silvery stomatal lines (see inset photo on opposite page). Abundant small staminate (male) cones release pollen and the round female cones mature to about 1.5 to 2.5 inches long in two years. Pairs of large seeds are held in depressions on individual cone scales; seeds are readily eaten by many birds and other wildlife species, and animal seed-caching, especially by pinyon jays (*Gymnorhinus cyanocephalus*), is the primary means of seed dispersal for the species.

Pinus monophylla grows in a semi-arid native range that runs from northern Baja California to southern and eastern California, Nevada, the southeastern corner of Idaho, western Utah, and parts of Arizona and New Mexico. It is cold hardy enough (USDA Zone 6, average annual minimum temperature -10 to 0°F [-23.3 to -17.8°C]) for Boston, but our much wetter climate may be part of the reason this pine has been difficult to grow at the Arboretum.

We have tried a number of *P. monophylla* accessions through the years, the first one in 1908, but we currently have no living specimens in the collections. The last one was accession 400-88-B, which was a repropagation (by grafting) of a 1964 accession (287-64), which came from seeds wild collected in Nevada. Accession 400-88-B was a handsome, healthy-looking specimen when I photographed it growing in the dwarf conifer terrace at the west end of the Leventritt Shrub and Vine Garden in May 2009 (opposite page). Unfortunately, just a few years later it went into severe decline and was removed; signs of root rot were noted on its removal. In its native range, single-leaf pine typically grows on very well-drained, gravelly slopes. The much greater annual rainfall and moister soils at the Arboretum may well have contributed to the demise of this and other specimens.

This unique pine species will certainly return to the Arboretum soon. *Pinus monophylla* is one of the approximately 400 taxa targeted for acquisition in the ongoing Campaign for the Living Collections (see the complete list in *Arnoldia* 73/3). We already have three seed accessions collected last year in Utah that are currently undergoing stratification in the Dana Greenhouses. And when we do have young single-leaf pines ready to move to the grounds, special care will be taken to place them in a site where, ideally, they will thrive for many years.

Nancy Rose is the editor of *Arnoldia.*

R. C. Steadman.
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